EPA-450/4-77-001
OCTOBER 1977
(OAQPS NO. 1.2-029 R)

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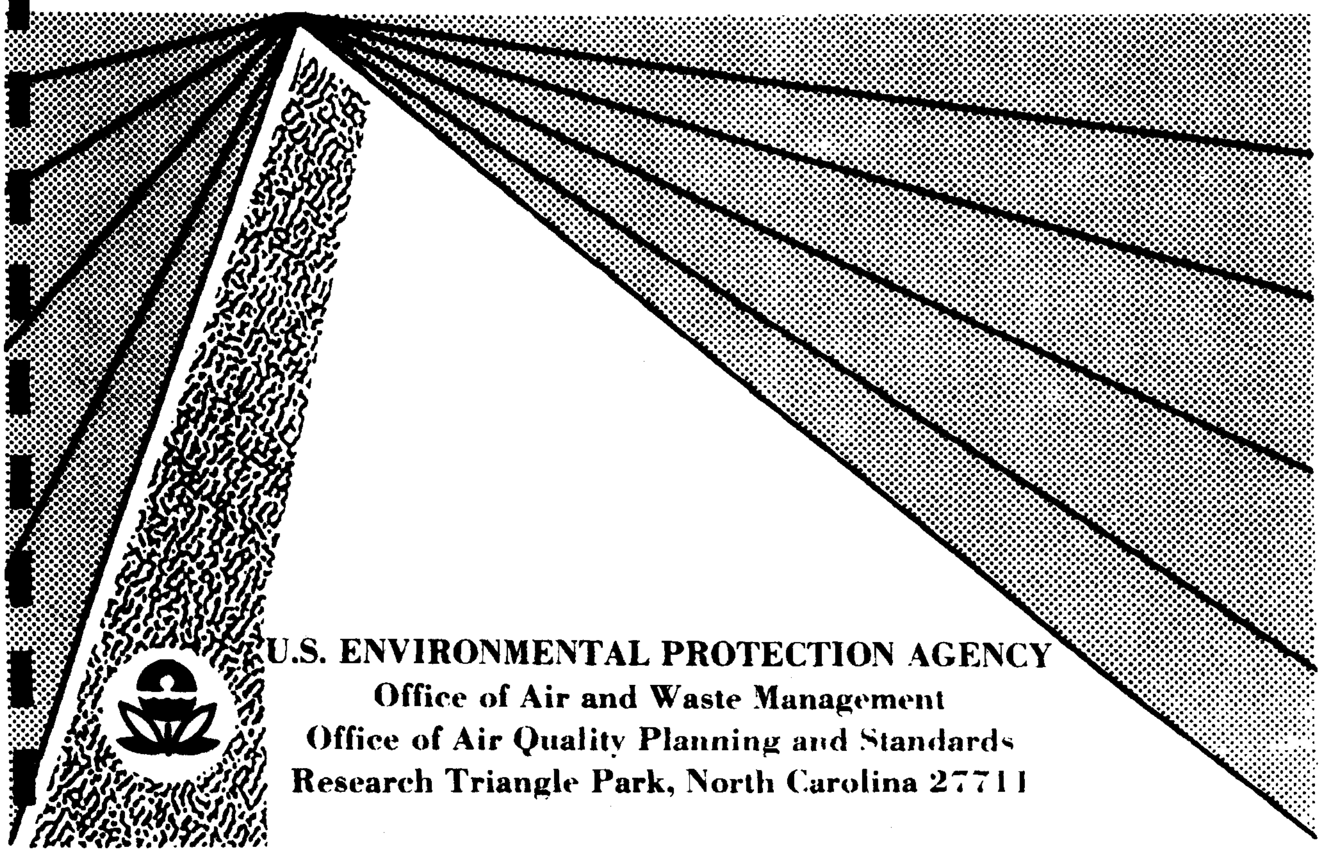
PROCEDURES FOR EVALUATING AIR QUALITY IMPACT OF NEW STATIONARY SOURCES



U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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PROCEDURES FOR EVALUATING AIR QUALITY IMPACT OF NEW STATIONARY SOURCES

by

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October 1977

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Publication No. EPA-450/4-77-001

OAQPS Guideline No. 1.2-029 R

FOREWORD

Through the publication of Guidelines for Air Quality Maintenance Planning and Analysis, the U.S. Environmental Protection Agency provides State and local agencies with information and guidance for the preparation of Air Quality Maintenance Plans required under 40 CFR 51. The volumes in this series are:

Volume 1: Designation of Air Quality Maintenance Areas

Volume 2: Plan Preparation

Volume 3: Control Strategies

Volume 4: Land Use and Transportation Consideration

Volume 5: Case Studies in Plan Development

Volume 6: Overview of Air Quality Maintenance Area Analysis

Volume 7: Projecting County Emissions

Volume 8: Computer-Assisted Area Source Emissions Gridding Procedure

Volume 9: Evaluating Indirect Sources

Volume 10: Procedures for Evaluating Air Quality Impact of New Stationary Sources (original version titled "Reviewing New Stationary Sources")

Volume 11: Air Quality Monitoring and Data Analysis

Volume 12: Applying Atmospheric Simulation Models to Air Quality Maintenance Areas

Volume 13: Allocating Projected Emissions to Sub-County Areas

Appendixes A and B

Supplement: Accounting for New Source Performance Standards

Volume 14: Designated Air Quality Maintenance Areas

Additional volumes may be issued.

PREFACE

This document is a revision of an earlier guideline[1] for applying screening techniques to estimate the air quality impact of new (proposed) stationary sources. The revision is in a more readily useable format and incorporates changes and additions to the technical approach. Also, a simple screening procedure has been added. The techniques are applicable to chemically stable, gaseous or fine particulate pollutants. An important advantage of the techniques is that a sophisticated computer is not required. A pocket or desk calculator will generally suffice.

If the analysis indicates that a more refined analysis is required, the user is directed to the Guideline on Air Quality Models[2].

ACKNOWLEDGMENTS

Credit is due Mr. Russell F. Lee, Project Officer for EPA on the preparation of the original version of this document, who continued to provide valuable technical assistance for this revision. Considerable support and insight were also provided by Messrs. James L. Dicke, Joseph A. Tikvart and William H. Keith.

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1. INTRODUCTION

Pursuant to Clean Air Act requirements for new sources, addressed in Title 40 of the Code of Federal Regulations (40 CFR 51.18: Review of New Sources and Modifications), States are required to enact legally enforceable review procedures to prevent the construction of pollutant sources that would result in noncompliance with an approved State control strategy, or would cause or contribute to ambient concentrations in excess of National Ambient Air Quality Standards. A review procedure for a "major" new stationary source[3] must include an air quality analysis to estimate the impact of the source on ambient air quality. This document presents a three-phase approach* that is applicable to the air quality analysis:

Phase 1. Apply a simple screening procedure (Section 4.1) to determine if either (1) the source clearly poses no air quality problem or (2) the potential for an air quality problem exists.

Phase 2. If the simplified screening results indicate a potential threat to air quality, further analysis is warranted, and the detailed screening (basic modeling) procedures described in Sections 4.2 through 4.5 should be applied.

Phase 3. If the detailed screening results or other factors indicate that a more refined analysis is necessary, refer to the Guideline on Air Quality Models[2].

The simple screening procedure (Phase 1) is applied to determine if the source poses a potential threat to air quality. The purpose of applying a simple screening procedure is to conserve resources by eliminating from further consideration those sources that clearly will not

*The techniques described herein can also be used, where appropriate, to review sources to prevent significant air quality deterioration, addressed in 40 CFR 52.21 (Significant Deterioration of Air Quality).

cause or contribute to ambient concentrations in excess of short-term air quality standards or allowable concentration increments. A relatively large degree of "conservatism" is incorporated in that screening procedure to provide reasonable assurance that maximum concentrations will not be underestimated.

If the source is not eliminated by the simple screening procedure, a detailed screening analysis is then conducted (Phase 2). The Phase 2 analysis will yield a somewhat conservative first approximation (albeit less conservative than the simple screening estimate) of the source's maximum impact on air quality. If the Phase 2 analysis indicates that the new source does not pose an air quality problem, further modeling may not be necessary. However, there are situations in which analysis beyond the scope of this document (Phase 3) may be required; for example, when:

1. The accuracy of the estimated concentrations must be maximized (e.g., if the results of the Phase 2 analysis indicate a potential air quality problem).
2. The source configuration is complex.
3. Emission rates are highly variable.
4. Pollutant dispersion is significantly affected by nearby terrain features or large bodies of water.

In most of those situations, more refined analytical techniques, such as computer-based dispersion models[2], can be of considerable help in estimating air quality impact.

In all cases, particularly when proceeding beyond the scope of this guideline, the services of knowledgeable, well-trained air pollution engineers, meteorologists and air quality analysts should be engaged. An air quality simulation model applied improperly can lead to serious misjudgments regarding the source impact.

2. SOURCE DATA

In order to estimate the impact of a stationary point source on air quality, certain characteristics of the source must be known. As a minimum, the following information should generally be available:

- Pollutant emission rate;
- Stack height;
- Stack gas temperature and volume flow rate (for plume rise calculations);
- Location of the point of emission with respect to surrounding topography, and the character of that topography;
- A detailed description of all structures in the vicinity of (or attached to) the stack in question. (See the discussion of aerodynamic downwash in Procedure 4(f) on page 4-18.)
- Similar information from other significant sources in the vicinity of the subject source (or air quality data or dispersion modeling results that demonstrate the air quality impact of those sources).

2.1 Emissions

The analysis of air quality impact requires that the emissions from each source be completely characterized. If the pollutants are not emitted at a constant rate (most are not), information should be obtained on how emissions vary with season, day of the week, and hour of the day. In most cases, emission rates vary with the source production rate or rate of fuel consumption. For example, for a coal-fired power plant, emissions are related to the kilowatt-hours of electricity produced, which is proportional to the tonnage of coal used to produce the electricity. If pollutant emission data are not directly available, emissions can be estimated from fuel consumption or production rates by multiplying the rates by appropriate emission factors.[4,5] Emission factors can be determined using three different methods. They are listed below in decreasing order of confidence:

1. Stack-test results or other emission measurements from an identical or similar source.
2. Material balance calculations based on engineering knowledge of the process.
3. Emission factors derived for similar sources or obtained from a compilation by the U.S. Environmental Protection Agency.[5]

In cases where emissions are reduced by control equipment, the effectiveness of the controls must be accounted for in the emissions analysis. The source operator can estimate control effectiveness in reducing emissions and how this effectiveness varies with changes in plant operating conditions. EPA Report No. APTD-1570[6] is a compilation of the types of control and control efficiencies for a variety of types of sources that are reported in the National Emissions Data System (NEDS). More detailed guides to the available types and degrees of control may be found in standard references.[7-16]

2.2 Merged Parameters for Multiple Stacks

Sources that emit the same pollutant from several similar stacks that are within about 100 meters of each other may be analyzed by treating all of the emissions as coming from a single representative stack[4]. For each stack compute the parameter K:

$$K = \frac{hVT_s}{Q}$$

where K = an arbitrary parameter accounting for the relative influence of stack height, plume rise, and emission rate on concentrations

h = stack height (m)

$V = (\pi/4)\ d^2\ v_s$ = stack gas volume flow rate (m^3/sec)

d = stack exit diameter (m)

v_s = stack gas exit velocity (m/sec)

T_s = stack gas exit temperature (K)

Q = pollutant emission rate (g/sec)

The stack that has the lowest value of K is used as a "representative" stack. Then the sum of the emissions from all stacks is assumed to be emitted from the representative stack; i.e., the equivalent source is characterized by h_1, V_1, T_{s1} and Q, where subscript 1 indicates the representative stack and $Q = Q_1 + Q_2 + \ldots + Q_n$.

The parameters from dissimilar stacks should be merged with caution. For example, if the stacks are located more than about 100 meters apart, or if stack heights or volume flow rates differ by more than about 20 percent, the resulting estimates of concentrations due to the merged stack procedure may be unacceptably high.

2.3 Topographic Considerations

It is important to study the topography in the vicinity of the source being analyzed. Topographic features, through their effects on plume behavior, will sometimes be a significant factor in determining ambient ground-level pollutant concentrations. Important features to note are the locations of large bodies of water, elevated terrain, valley configurations, and general terrain roughness in the vicinity of the source.

Section 4.5.1 provides guidance on estimating ambient concentrations at receptors located on elevated terrain features. Any other topographic considerations are beyond the scope of this guideline.

3. METEOROLOGICAL DATA

Each computational procedure given in Section 4 for estimating the impact of a stationary source on air quality requires data on one or more of the following meteorological parameters:

- Wind speed and direction
- Stability class
- Mixing height
- Temperature

A discussion of each of those parameters and their relation to the procedures of Section 4 follows.

3.1 Wind Speed and Direction

Wind speed and direction data are required to estimate short-term peak and long-term average concentrations. The wind speed determines (1) the amount by which a plume is diluted as it leaves the stack and (2) the plume rise downwind of the stack. These factors, in turn, affect the magnitude of and distance to the maximum ground-level concentration.

Most wind data are collected near ground level. The wind speed at plume height can be estimated from the following power law equation:

$$u = u_1 \left[\frac{h}{z_1} \right]^{p}$$

where:

u = the wind speed (m/sec) at height h,

u_1 = the wind speed at the anemometer height z_1, and

p = the stability-related exponent from Table 3-1.

Table 3-1. WIND PROFILE EXPONENT AS A FUNCTION OF ATMOSPHERIC STABILITY

Stability Class	Exponent
A	0.10
B	0.15
C	0.20
D	0.25
E, F	0.30

The wind direction is an approximation to the direction of transport of the plume. The variability of the direction of transport over a period of time is a major factor in estimating ground-level concentrations averaged over that time period.

Wind speed and direction data from National Weather Service, Air Weather Service, and Naval Weather Service stations are available from the National Climatic Center, Asheville, North Carolina. Wind data are often also recorded at existing plant sites and at air quality monitoring sites. It is important that the equipment used to record such data be properly designed, sited, and maintained to record data that are reasonably representative of the direction and speed of the plume.

3.2 Stability

Stability categories, as depicted in Tables 3-1 and 3-2, are measures of atmospheric turbulence. The stability category at any given time will

Table 3-2. KEY TO STABILITY CATEGORIES

Surface Wind Speed at a Height of 10m (m/sec)	Day Incoming Solar Radiation* (Insolation)			Night	
	Strong	Moderate	Slight	Thinly Overcast or $\geq$ 4/8 Low Cloud Cover	$\leq$ 3/8 Cloud Cover
< 2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

The neutral class (D) should be assumed for all overcast conditions during day or night.

*Appropriate insolation categories may be determined through the use of sky cover and solar elevation information as follows:

Sky Cover	Solar Elevation Angle > 60°	Solar Elevation Angle $\leq$ 60° But >35°	Solar Elevation Angle $\leq$ 35° But > 15°
4/8 or Less or Any Amount of High Thin Clouds	Strong	Moderate	Slight
5/8 to 7/8 Middle Clouds (7000 feet to 16,000 foot base)	Moderate	Slight	Slight
5/8 to 7/8 Low Clouds (less than 7000 foot base)	Slight	Slight	Slight

depend upon static stability (the change in temperature with height), thermal turbulence (caused by heating of the air at ground level), and mechanical turbulence (a function of wind speed and surface roughness). It is generally estimated by a method given by Turner[17], which requires information on solar elevation angle, cloud cover, ceiling height, and wind speed (see Table 3-2).

The solar elevation angle is a function of the time of year and the time of day, and is presented in charts in the Smithsonian Meteorological Tables[18]. The hourly weather observations of the National Weather Service include cloud cover, ceiling height, and wind speed. These data are available from the National Climatic Center.

For computation of seasonal and annual concentrations, a joint frequency distribution of stability class, wind direction, and wind speed (stability wind rose) is needed. Such frequency distributions can be obtained from the National Climatic Center.

3.3 Mixing Height

The mixing height is the distance above the ground to which relatively free vertical mixing occurs in the atmosphere. When the mixing height is low (but still above plume height) ambient ground-level concentrations will be relatively high because the pollutants are prevented from dispersing upward. For estimating long-term average concentration, it is generally adequate to use an annual-average mixing height rather than daily values.

Mixing height data are generally derived from surface temperatures and from the twice-daily upper air soundings which are made at selected

National Weather Service Stations. The procedure used to determine mixing heights is one developed by Holzworth[19]. Tabulations and summaries of mixing height data can be obtained from the National Climatic Center.

3.4 Temperature

Ambient air temperature must be known in order to calculate the amount of rise of a buoyant plume. Plume rise is proportional to a fractional power of the temperature difference between the stack gases and the ambient air (see Section 4.2). Ambient temperature data are collected hourly at National Weather Service Stations, and are available from the National Climatic Center.

4. ESTIMATING SOURCE IMPACT ON AIR QUALITY

A three-phase approach, as discussed in the Introduction, is recommended for estimating the air quality impact of a proposed major source:

Phase 1. Simple screening analysis

Phase 2. Detailed screening (basic modeling) analysis

Phase 3. Refined modeling analysis*

This section presents the simple screening procedure (Section 4.1) and the detailed screening procedures (Sections 4.2 through 4.5). All of the procedures, with the partial exception of Section 4.5.1, are based upon the bi-variate Gaussian dispersion model assumptions described in the Workbook of Atmospheric Dispersion Estimates[17]. A consistent set of units (meters, grams, seconds) is used throughout:

Distance (m)

Pollutant Emission Rate (g/sec)

Pollutant Concentration (g/m^3)

Wind Speed (m/sec)

4.1 Simple Screening Procedure

The simple screening procedure is the "first phase" that is recommended when assessing the air quality impact of a new point source. The purpose of this screening procedure is to eliminate from further consideration those sources that clearly will not cause or contribute to ambient condentrations in excess of short-term air quality standards.

*The Phase 3 analysis is beyond the scope of this guideline, and the user is referred to the Guideline on Air Quality Models[2].

The scope of the procedure is confined to point sources, plume heights of 10 to 300 meters and concentration averaging times of 1 to 24 hours. The procedure is particularly useful for sources where the short-term air quality standards are the "controlling" ones; i.e., in cases where meeting the short-term standards provides good assurance of meeting the annual standard for that pollutant. Elevated point sources (i.e., sources for which the emission points are well above ground level) are often in that category, particularly when they are remote from other sources.

When applying the screening procedure to elevated point sources, the following assumptions apply:

1. No aerodynamic downwash of the effluent plume occurs. (Refer to Procedure 4(f) on page 4-18 to determine if downwash is a potential problem.)

2. The plume does not intercept terrain. (Refer to Section 4.5.1 to determine if terrain may be intercepted.)

If the potential for either of those problems is found to exist, the calculation procedure described in the indicated section should be applied (in addition to the screening procedure described in this section) to estimate the resulting maximum ground-level concentration. Except for sources close to ground level, the calculation procedures for aerodynamic downwash and terrain interception will tend to yield higher concentration estimates than the simple screening procedure.

The screening procedure utilizes the Gaussian dispersion equation to estimate the maximum 1-hour ground-level concentration likely to result from the source in question (Computations 1-6 below). To obtain concentrations for other averaging times up to 24 hours, multiply the one-hour value by an appropriate factor (Computation 7). Then account for background concentrations (Computation 8) to obtain a total concentration estimate. That estimate is then used, in conjunction with any downwash or terrain estimates, to determine if further analysis of the source impact is warranted (Computation 9):

1. Compute the normalized plume rise ($u\Delta h$), utilizing the procedure described in Step 1 on page 4-7.

2. Divide the $u\Delta h$ value obtained in (1) by each of five wind speeds (u = 0.5, 1.0, 2.0, 3.0 and 5.0 m/sec) to estimate the actual plume rise (Δh) for each wind speed:

$$\Delta h = \frac{(u\Delta h)}{u} \quad \text{meters}$$

3. Compute the plume height (H) that will occur during each wind speed by adding the respective plume rises to the stack height (h_s):

$$H = h_s + \Delta h \qquad \text{meters}$$

4. For each plume height computed in (3), estimate a $\chi u/Q$ value from Figure 4-1.

5. Divide each $\chi u/Q$ value by the respective wind speed to determine the corresponding χ/Q values:

$$\chi/Q = \frac{\chi u/Q}{u}$$

6. Multiply the maximum χ/Q value obtained in (5) by the emission rate Q (g/sec), and incorporate a factor of 2 margin of safety, to obtain the maximum 1-hour ground-level concentration χ_1 (g/m^3) due to emissions from the stack in question:

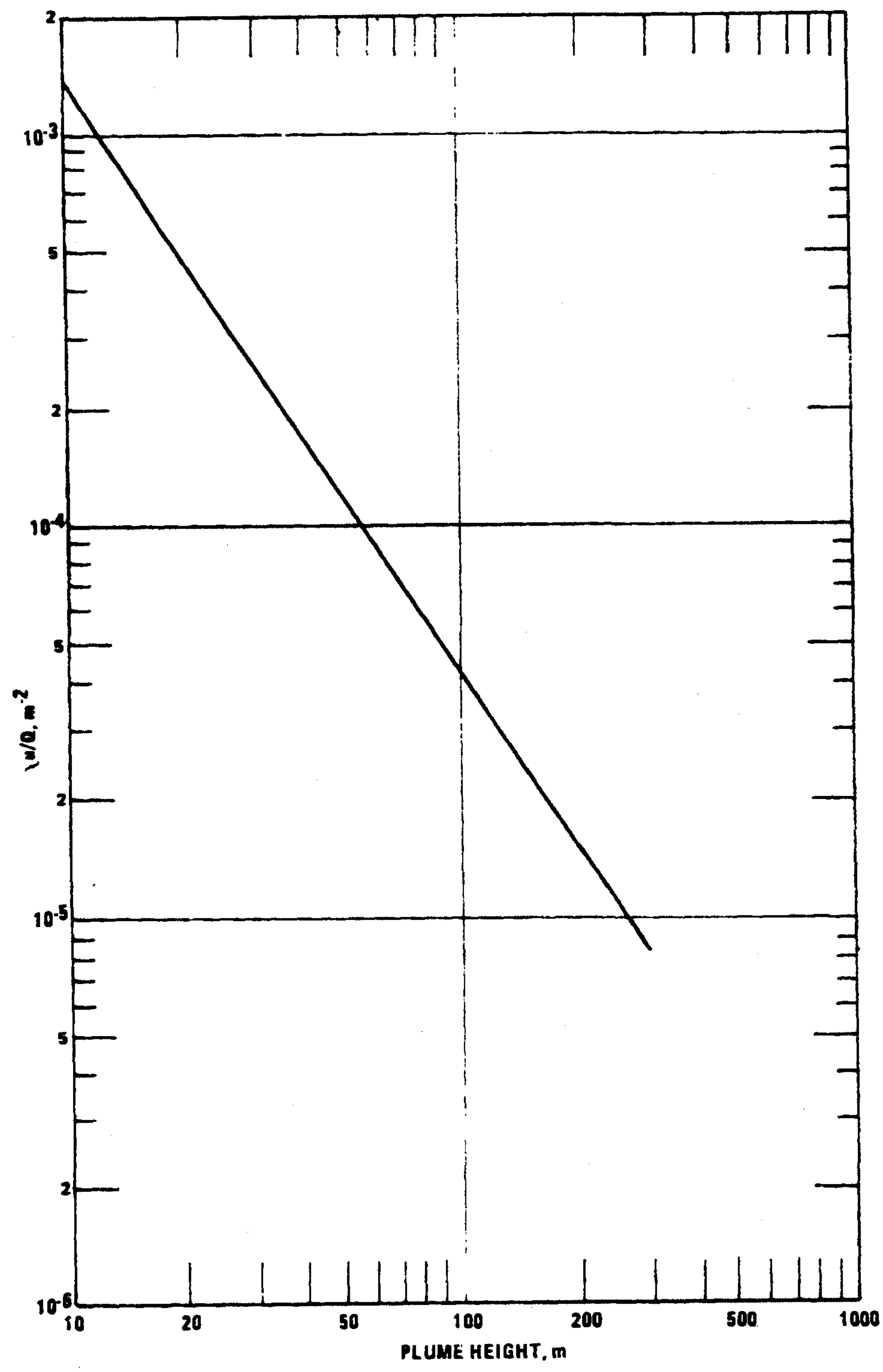

Figure 4-1. Maximum $\chi u/Q$ as a function of plume height, H (for use only with the simple screening procedure).[20]

$$\chi_1 = 2Q[\chi/Q]$$

The margin of safety is incorporated in the screening procedure to account for the potential inaccuracy of concentration estimates obtained through calculations of this type.

If more than one stack is being considered, and the procedure for merging parameters for multiple stacks is not applicable (Section 2.2), (1) through (6) must be applied for each stack separately. The maximum values (χ_1) found for each stack are then added together to estimate the <u>total</u> maximum 1-hour concentration.

7. To obtain a concentration estimate (χ_p) for an averaging time greater than one hour, multiply the one-hour value by an appropriate factor R. (See the discussion in Step 5 on page 4-20, which addresses multiplication factors for averaging times longer than one hour.)

$$\chi_p = \chi_1 (R)$$

8. Next, contributions from other sources (B) should be taken into account, yielding the final screening procedure concentration estimate χ_{max} (g/m^3):

$$\chi_{max} = \chi_p + B$$

Guidance on estimating concentrations due to other sources is provided in Section 4.5.2.

9. Based on the estimate of χ_{max} and (if applicable) estimates of concentrations due to downwash or terrain problems, determine if further

analysis of the source is warranted: If any of the estimated concentrations exceeds the air quality level of concern (e.g., an air quality standard), proceed to Section 4.2 for further analysis. If the concentrations are below the level of concern, the source can be safely assumed to pose no threat to that air quality level, and no further analysis is necessary.*

4.2 Estimating Maximum Short-Term Concentrations

The basic modeling procedures described in the remainder of this guideline comprise the recommended "second phase" (or detailed screening) that may be used in assessing new source air quality impact. The procedures are intended for application in those cases where the simple screening procedure (first phase) indicates a potential air quality problem.

Two parallel approaches are offered. Primary emphasis is given to an approach that can be applied without the aid of a computer (a pocket or desk calculator will suffice). The alternative approach, which is only applicable in certain cases, is to use a series of computer programs that has been made available by EPA. The series of programs, referred to as UNAMAP ("User's Network for Applied Modeling of Air Pollution"), is available through a commercial teleprocessing network and it can be accessed by remote terminal. Alternatively, a magnetic computer tape of the UNAMAP programs may be pruchased from the National Technical Information Service. (See Appendix A for more information about UNAMAP).

*A relatively large degree of "conservatism" is incorporated in the simple screening procedure and in the procedures for downwash and terrain situations to provide reasonable assurance that maximum concentrations will not be underestimated.

This section (4.2) presents the basic procedures for estimating maximum short-term concentrations for specific meteorological situations. In Steps 1-3, plume rise[21,22,23] and critical wind speed are computed. In Step 4, maximum 1-hour concentrations are estimated. In Step 5, the 1-hour concentrations are used to estimate concentrations for averaging times up to 24 hours. Contributions from other sources are accounted for in Step 6.

If aerodynamic downwash is a problem at the facility (see Procedure 4(f) on page 4-18) or if the UNAMAP computer programs are to be used, begin with Step 4. For area sources, refer to Section 4.5.2 (C) for guidance. Otherwise, proceed with Step 1:

Step 1. Estimate the normalized plume rise ($u\Delta h$) that is applicable to the source during neutral and unstable atmospheric conditions. First, compute a buoyancy term F:

$$F = \frac{g}{4} v_s d^2 \left[\frac{T_s - T_a}{T_s}\right]$$

$$= 3.12\ V \left[\frac{T_s - T_a}{T_s}\right]$$

where g = acceleration of gravity (9.8 m/sec^2)

v_s = stack gas exit velocity (m/sec)*

d = inside stack diameter (m)

T_s = stack gas temperature (K)*

*If stack gas temperature or exit velocity data are unavailable, they may be approximated from guidelines that present typical values for those parameters for existing plants[24].

T_a = ambient air temperature (K) (If no ambient temperature data are available, assume that T_a = 293 K.)

V = actual stack gas flow rate (m^3/sec)

Normalized plume rise is then given by:

$u\Delta h = 21.4F^{3/4}$ when $F < 55\ m^4/sec^3$

$u\Delta h = 38.7F^{3/5}$ when $F \geq 55\ m^4/sec^3$

Step 2. Estimate the critical wind speed (u_c) applicable to the source during neutral and unstable atmospheric conditions. The critical wind speed is a function of two opposing effects that occur with increasing wind speed; namely, increased dilution of the effluent as it leaves the stack (which tends to decrease the maximum impact on ground-level concentrations) and suppression of plume rise (tending to increase the impact). The wind speed at which the interaction of those opposing effects results in the highest ground-level concentration is the critical wind speed.

The critical wind speed can be estimated through the following approximation:

$$u_c = \frac{(u\Delta h)}{h_s}$$

Step 3. For sources where the height of emission is greater than or equal to 50 meters, proceed to Step 4. If the emission height is less than 50 meters, stable atmospheric conditions may be critical. The stable case plume rise (Δh) should be estimated as the smaller of the following two values: (The second value is the limiting case for calm and near calm conditions.)

$$\Delta h = 2.4\left[\frac{F \quad T_a}{ug \frac{\Delta\theta}{\Delta z}}\right]^{1/3}$$

$$\Delta h = 5F^{1/4}\left[\frac{g}{T_a}\frac{\Delta\theta}{\Delta z}\right]^{-3/8}$$

The value $\frac{\Delta\theta}{\Delta z}$ is the change in potential temperature with height. If typical values of $\frac{\Delta\theta}{\Delta z}$ are not known for the site, a value of 0.02 K/m for E stability, and 0.035 K/m for F stability may be used for sources with stacks less than about 100m high. For stacks more than 100m high, use 0.01 K/m and 0.02 K/m respectively.

Step 4. Estimate maximum 1-hour concentrations that will occur during various dispersion situations. (Note: UNAMAP users begin with this step.) First, using Table 4-1 as a guide, determine the dispersion situations and corresponding calculation procedures applicable to the source being considered. Then apply the applicable calculation procedures, which are described on the following pages, in order to estimate maximum 1-hour concentrations. Then proceed to Step 5 on page 4-20.

Table 4-1. CALCULATION PROCEDURES TO USE WITH VARIOUS STACK HEIGHTS

Height of Emission (stack height)	Applicable Calculation Procedures
$h_s \geq 50$ meters	Looping 4(a) Limited mixing 4(b) Coning 4(c) Fumigation 4(e)
$10 \leq h_s < 50$ meters	Looping 4(a) Coning 4(c) Fanning 4(d) Fumigation 4(e)
$h_s < 10$ meters	Coning 4(c) Fanning 4(d)
$h_s < h_b + 1.5a$	Downwash 4(f)

Procedure 4(a): Looping Plume

During very unstable conditions the plume from a stack will be mixed to ground level relatively close to the source, resulting in high short-term concentrations. Such a plume is called a looping plume because of its appearance.

Calculation Procedure:

1. Estimate plume height H, using the values of $u\Delta h$ and u_c computed in Steps 1 and 2 on pages 4-7 and 4-8:

$$H = 2\ h_s \text{ if } u_c \leq 3.0 \text{ m/sec}$$

$$H = h_s + \frac{[u\Delta h]}{3.0} \text{ if } u_c > 3.0 \text{ m/sec}$$

2. Determine the maximum $\chi u/Q$ from Figure 4-2 (for the rural case) using the A stability curve, or from Figure 4-3 (urban case) using the A-B stability curve.

3. Compute the maximum 1-hour concentration χ_1:

$$\chi_1 = \frac{Q}{u_c} [\chi u/Q]$$

If the computed value of u_c is greater than 3, set it equal to 3.

An alternate procedure using the UNAMAP series of computer programs may be applied:

1. Using the PTMAX program, enter the emission rate, stack height, stack gas temperature and either the actual stack gas volume flow rate or the stack diameter and stack gas exit velocity.

2. Assume stability class A.

3. Select the highest 1-hour concentration printed.

Procedure 4(b): Limited Mixing

Limited mixing (also called plume trapping) occurs when a stable layer aloft limits the vertical mixing of the plume. The result can be relatively high ground-level concentrations that may persist for hours. The highest concentrations occur when the mixing height is at or slightly above the plume height.

Calculation Procedure:

1. Estimate plume height H, using the $u\Delta h$ value computed in Step 1 on page 4-7:

$$H = h_s + \frac{[u\Delta h]}{2.5}$$

The value 2.5 represents the assumed critical wind speed (m/sec).

2. Using the curve for stability C on Figure 4-2 (rural) or Figure 4-3 (urban), determine the maximum 1-hour $\chi u/Q$ for that plume height.

3. Compute the maximum 1-hour concentration χ_1:

$$\chi_1 = 2Q[\chi u/Q]/2.5$$

The value 2 reflects the assumption that the maximum concentration may be double the maximum that would occur if there were no restriction to vertical mixing.

Alternate procedure using the UNAMAP programs:

1. Using the PTMAX program, enter emission rate, stack height, stack gas temperature and either the actual stack gas volume flow, or the stack diameter and stack gas exit velocity.

2. Assume stability class C.

3. Select the 1-hour concentration for the 2.5 m/sec wind speed, and double the value.

Procedure 4(c): Coning Plume

Some buoyant plumes will have their greatest impact on ground-level concentrations during neutral or near-neutral conditions (coning plume).

Calculation procedure:

1. Assume that plume height is equal to twice the stack height:

$$H = 2\ h_s$$

2. Using the curve for stability C on Figure 4-2 (rural) or Figure 4-3 (urban), determine the maximum 1-hour $\chi u/Q$ for that plume height.

3. Compute the maximum 1-hour concentration χ_1, using the value of u_c computed in Step 2 on page 4-8:

$$\chi_1 = Q[\chi u/Q]/u_c$$

If u_c is substantially greater than wind speeds that one could reasonably expect at plume height, a more reasonable critical wind speed (u_c') may be specified, and the equation $H = h_s + [u\Delta h]/u_c'$ used for Step 1 and $\chi_1 = Q[\chi u/Q]/u_c'$ used for Step 3.

Caution: Wind speeds aloft are generally higher than at the surface, so that a wind speed that is rare at the surface may be relatively common at plume height.

Alternate procedure using the UNAMAP computer programs:

1. Using the PTMAX program, enter the emission rate, stack height, stack gas temperature, and either the actual stack gas volume flow or the stack diameter and stack gas exit velocity.

2. Assume stability class C.

3. Select the highest 1-hour concentration printed.

Procedure 4(d): Fanning Plume

Low-level sources (i.e., sources with stack heights less than about 50 m) sometimes produce the highest concentrations during stable atmospheric conditions. Under such conditions, the plume's vertical spread is severely restricted and horizontal spreading is also reduced. This results in what is called a fanning plume.

Calculation procedures:

A. For low-level sources with some plume rise, calculate the concentration as follows:

1. Compute the plume height (H) that will occur during F stability (for rural cases) or E stability (for urban cases) and for wind speeds of 2, 3 and 5 m/sec. Use the stable-case plume rise (Δh) values obtained in Step 3 on page 4-8:

$$H = h_s + \Delta h$$

2. For each wind speed and stability considered in (1), find the maximum 1-hour $\chi u/Q$ from Figure 4-2 (rural) or 4-3 (urban). Compute the maximum 1-hour concentration for each case, using

$$\chi_1 = [\chi u/Q]\ Q/u$$

and select the highest concentration computed.

B. For low-level sources with no plume rise ($H = h_s$), find the maximum 1-hour $\chi u/Q$ from Figure 4-2 (rural case--assume F stability) or

4-3 (urban case--assume E stability). Compute the maximum 1-hour concentration, assuming that u = 1 m/sec:

$$\chi_1 = [\chi u/Q] \; Q/u$$

Alternate procedure using the UNAMAP computer programs:

1. Using PTMAX, follow the procedure given for the "Looping Plume Model," except apply the procedure for stabilities E and F.

2. If the minimum distance at which the concentration is of concern (e.g., the distance to the closest point at which the general public has access) is greater than the distances indicated in the PTMAX program output, apply the PTDIS model (see Appendix A) and specify the minimum distance of concern.

3. Select the highest of the 1-hour concentrations computed.

Procedure 4(e): Fumigation

(Note: UNAMAP is not applicable to the fumigation situation.) Fumigation occurs when a plume that was originally emitted into a stable layer is mixed rapidly to ground-level when unstable air below the plume reaches plume level. Fumigation can cause very high ground-level concentrations. Typical situations in which fumigation occurs are:

1. "Burning off" of the nocturnal radiation inversion by solar warming of the ground surface;

2. Advection of pollutants from a stable rural environment to a turbulent urban environment;

3. "Shoreline fumigation" caused by advection of pollutants from a stable marine environment to an unstable inland environment.

The following procedure is for estimating concentrations only due to the first type of fumigation listed above. (The second and third types can also result in high concentrations[25]. However, procedures for estimating concentrations during those situations are beyond the scope of this document.)

1. Compute the plume height (H) that will occur during F stability and a wind speed of 2.5 m/sec:

$$H = h_s + \Delta h$$

To obtain a value for Δh, use the procedure described in Step 3 on page 4-8.

2. Using Table 4-2 (derived from Turner's fumigation procedure[17]), estimate the downwind distance at which the maximum fumigation concentration is expected to occur. (If this distance is less than about 2 kilometers, fumigation concentrations are not likely to significantly exceed the limited mixing concentrations estimated in Procedure 4(b).)

3. At the distance estimated in (2), determine the values of σ_y and σ_z for F stability from Figures 4-4 and 4-5.

4. Compute the maximum concentration (χ_f), using the following equation[17]:

$$\chi_f = \frac{Q}{\sqrt{2\pi}\, u(\sigma_y + H/8)\ (H + 2\sigma_z)}$$

The concentration χ_f can be expected to persist for about 30 to 90 minutes. It is not recommended that the computed concentration be extrapolated to longer averaging times.

Table 4-2. DOWNWIND DISTANCE (km) TO THE MAXIMUM GROUND-LEVEL FUMIGATION CONCENTRATION AS A FUNCTION OF STACK HEIGHT (h) AND PLUME HEIGHT (H); STABILITY CLASS F AND WIND SPEED = 2.5 m/sec

h \ H	< 60	60	75	100	125	150	175	200	225	250	275	300
10	(< 2)	2	3	7	10	14	18	22	26	31	36	41
30	(< 2)	2	3	6	9	13	17	22	26	31	36	41
50	(< 2)	(< 2)	2	6	9	13	17	21	26	31	36	41
75	-	-	(< 2)	5	8	12	16	20	25	30	35	40
100	-	-	-	3	6	10	15	19	24	29	34	39
125	-	-	-	-	4	8	13	17	22	27	32	38
150	-	-	-	-	-	5	11	15	20	25	30	36
175	-	-	-	-	-	-	7	12	18	23	28	34
200	-	-	-	-	-	-	-	9	15	21	26	32
225	-	-	-	-	-	-	-	-	11	17	23	29
250	-	-	-	-	-	-	-	-	-	13	19	25
275	-	-	-	-	-	-	-	-	-	-	15	21
300	-	-	-	-	-	-	-	-	-	-	-	17

Procedure 4(f): Downwash

(Note: UNAMAP is not applicable to the downwash situation.) In some cases, the aerodynamic turbulence induced by a building will cause a pollutant emitted from an elevated source to be mixed rapidly toward the ground (downwash), resulting in higher ground-level concentrations immediately to the lee of the building than would otherwise occur. Thus, when assessing the impact of a source on air quality, the possibility of downwash problems should be investigated. If downwash is found to be a potential problem, its effect on air quality should be estimated.

The best approach to determine if downwash will be a problem at a proposed facility is to conduct observations of effluent behavior at a similar facility. If such a study is not feasible, wind tunnel study is recommended, particularly if the facility has a complex configuration. If neither of the above approaches is feasible, and if the facility has a simple configuration (e.g., a stack adjacent or attached to a single rectangular building), a simple rule-of-thumb[26] may be applied to determine the stack height (h_s) necessary to avoid downwash problems:

$$h_s \geq h_b + 1.5\ a,$$

where h_b is building height and "a" is the lesser of either building height or maximum building width. In other words, if the stack height is equal to or greater than h_b + 1.5 a, downwash is unlikely to be a problem.

If there is more than one stack at a given facility, the above rule may be successively applied to each stack. If more than one building is involved, the rule may be successively applied to each building. For relatively complex source configurations the rule may not be applicable, particularly when the building shapes are much different than the simple rectangular building for which the above equation was derived.

If it is determined that the potential for downwash exists, the next step is to estimate the maximum ground-level pollutant concentrations that will occur as a result of the downwash. The impact of downwash on ground-level concentrations will be a function of many factors, including building configuration, emission characteristics, stack height, wind speed and wind direction. Generally, however, downwash will have its greatest impact when the effluent:

(1) has relatively little initial buoyancy or vertical momentum, and

(2) is released from a point on the building itself or from a stack that is close to the building (within about 3 to 5 building heights) and substantially below the height (computed above) that is necessary to avoid downwash.

In such a case, which may be considered a "worst case" condition for downwash, the maximum 1-hour impact on ground-level concentrations (χ_1) will occur within a few building heights of the downwind edge of the building, and can be estimated by the following simple approximation[27]

$$\chi_1 = \frac{Q}{1.5\,(A)(u)}$$

where Q is the maximum emission rate likely to occur for the averaging time of concern, A is the cross-sectional area of the building normal to the wind, and u is wind speed. For u, one should choose the lowest wind speed likely to result in entrainment of most or all of the pollutant into the downwash "cavity" in the lee of the building. If no data are available from which that minimum wind speed can be estimated, assume a speed of 3 m/sec for the worst case.

It is important to recognize that the above equation for χ_1 is only applicable to the worst case described above. (Even for the worst case, the equation will tend to overpredict ground-level concentrations, particularly for relatively tall sources.) For situations significantly different than the worst case, and for complex source configurations, a more detailed analysis is required[28, 29].

Step 5. Obtain concentration estimates for the averaging times of concern. The maximum 1-hour concentration is the highest of the concentrations estimated in Step 4. For averaging times greater than one hour, the maximum concentration will generally be less than that 1-hour value. The following discussion describes how that 1-hour value may be used to make an estimate of maximum concentrations for longer averaging times. (This does not apply to the fumigation case described in Procedure 4(e)).

The ratio between a longer-term maximum concentration and a 1-hour maximum will depend upon the duration of the longer averaging time, source characteristics, and local climatology and topography. Because of the many ways in which such factors interact, it is not practical to categorize all situations that will typically result in any specified ratio between the longer-term and 1-hour maxima. Therefore, ratios are presented here for a "general case" (where it is assumed that emissions are constant and there are no terrain or downwash problems), and the user is given some flexibility to subjectively adjust those ratios to represent more closely any particular point source:

Averaging Time	Multiplying Factor
3 hours	0.9 (± 0.1)
8 hours	0.7 (± 0.2)
24 hours	0.4 (± 0.2)

To obtain the estimated maximum concentration for a 3, 8 or 24-hour averaging time, multiply the 1-hour maximum by the given factor. The numbers in parentheses are recommended limits to which one may diverge from the multiplying factors representing the general case. For example, if aerodynamic downwash or terrain is a problem at the facility, or if the emission height is very low, it may be desirable to increase the factors (within the limits specified in parentheses). On the other hand, if the stack is relatively tall and there are no terrain or downwash problems, it may be appropriate to decrease the factors.

The multiplying factors listed above are based upon general experience with elevated point sources. The factors are only intended as a rough guide for estimating maximum concentrations for averaging times greater than one hour. A degree of conservatism is incorporated in the factors to provide reasonable assurance that maximum concentrations for 3, 8 and 24 hours will not be underestimated.

Step 6. Add the expected contribution from other sources to the concentration estimated in Step 5. Concentrations due to other sources can be estimated from measured data, or by computing the effect of existing sources on air quality in the area being studied. Procedures for estimating such concentrations are given in Section 4.5.2.

At this point in the analysis, a first approximation of maximum short-term ambient concentrations (source impact plus contributions from other sources) has been obtained. If concentrations at specified locations, long-term concentrations, or other special topics must be addressed, refer to applicable portions of Sections 4.3 to 4.5.

4.3 Short-Term Concentrations at Specified Locations

In Section 4.2, maximum concentrations are generally estimated without specific attention to the location(s) of the receptor(s). In some cases, however, it is particularly important to estimate the impact of a new source on air quality in specified (e.g., critical) areas. For example, there may be nearby locations at which high pollutant concentrations already occur due to other sources, and where a relatively small addition to ambient concentrations might cause ambient standards to be exceeded.

Each of the sources affecting a given location can be expected to produce its greatest impact during certain meteorological conditions.

The composite maximum concentration at that location due to the interaction of all the sources may occur under different meteorological conditions than those which produce the highest impact from any one source. Thus, the analysis of this problem can be difficult, and may require substantial use of high-speed computers.

Despite the potential complexity of the problem, some preliminary calculations can be made that will at least indicate whether or not a more detailed study is needed. For example, if the preliminary analysis indicates that the estimated concentrations are near or above the air quality standards of concern, a more detailed analysis will probably be required.

Calculation procedure (If the UNAMAP programs can be used, proceed to the paragraph following Step 10 below. Otherwise, proceed with Step 1.)

Step 1. Compute the normalized plume rise ($u\Delta h$), utilizing the procedure described in Step 1 on page 4-7.

Step 2. Divide the $u\Delta h$ value obtained above by each of several wind speeds (u = 1, 3, 5, 10, and 20 m/sec) to estimate the actual plume rise (Δh) associated with each wind speed:

$$\Delta h = \frac{(u\Delta h)}{u}$$

Step 3. Compute the plume height (H) that will occur during each wind speed by adding the respective plume rises to the stack height (h_s):

$$H = h_s + \Delta h$$

Step 4. For each stability class-wind speed combination listed below*, at the downwind distance of the "specified location," determine the $\chi u/Q$ value from Figures 4-6 through 4-9 (rural) or Figures 4-12 through 4-14 (urban). Note in those figures (see the captions) that very restrictive mixing heights are assumed, resulting in trapping of the entire plume within a shallow layer.

Stability Class	Wind Speed (m/sec)
A	1, 3
B	1, 3, 5
C	1, 3, 5, 10,
D	1, 3, 5, 10, 20

Step 5. (If the physical stack height is greater than 50 meters, Steps 5 and 6 may be skipped.) Compute plume heights (H) for stability classes E and F, for wind speeds of 1, 3 and 5 m/sec:

$$H = h_s + \Delta h$$

where Δh is the plume rise as computed in Step 3 on page 4-8.

*Only consider those stability-wind speed combinations that can exist for the length of time it takes the plume to travel to the location of interest, plus at least one hour. Refer to Table 4-3 for the maximum durations of each stability class.

Table 4-3. MAXIMUM DURATION OF STABILITY CLASSES FOR SELECTED LATITUDES AND DATES

Latitude	Date	Maximum Duration of Stability Class (Hours)*			
		A	B	C	E,F
30°N	Dec 22	0	2	7	16
	Feb 9, Nov 3	0	4	8	15
	Mar 8, Oct 6	0	6	9	14
	Apr 3, Sept 10	2	7	10	14
	May 1, Aug 12	4	8	11	13
	Jun 22	4	8	12	12
40°N	Dec 22	0	0	6	17
	Feb 9, Nov 3	0	1	7	16
	Mar 8, Oct 6	0	5	9	14
	Apr 3, Sept 10	0	6	10	13
	May 1, Aug 12	2	7	11	12
	Jun 22	4	8	12	11
50°N	Dec 22	0	0	2	18
	Feb 9, Nov 3	0	0	6	17
	Mar 8, Oct 6	0	1	8	15
	Apr 3, Sept 10	0	5	10	13
	May 8, Aug 6	2	7	11	11
	Jun 22	4	8	12	10

*Based on duration of solar angle above or below following limits: Class A - above 60°, Class B - above 35°, Class C - above 15°, Class E and F - below 0°. (Two hours have been added to the duration of solar angle below the horizon to account for the stable conditions that begin to occur about an hour before sunset and persist for an hour after sunrise.) For stability Classes A, B and C, the hours are centered on solar noon. Stability D can persist, in all the above cases, for periods in excess of 24 hours.

Step 6. For each stability class-wind speed combination considered in Step 5, at the downwind distance of the specified location, determine a $\chi u/Q$ value from Figures 4-10 and 4-11 (or Figure 4-15 for the urban case). Also, refer to the Step 4 footnote.

Step 7. For each $\chi u/Q$ value obtained in Step 4 (and Step 6 if applicable), compute χ/Q:

$$\chi/Q = [\chi u/Q]/u$$

Step 8. Select the largest χ/Q and multiply by the source emission rate (g/sec) to obtain a 1-hour concentration value (g/m^3):

$$\chi_1 = Q[\chi/Q]_{max}$$

Step 9. (This step is not applicable if the downwind distance to the specified location is either (1) less than 2 kilometers or (2) less than the distance to the maximum fumigation concentration, obtained from Table 4-2.) Compute the maximum 1-hour concentration, χ_f, that will occur due to fumigation (discussed in Procedure 4(e) on page 4-15) using the following equation[17]:

$$\chi_f = \frac{Q}{\sqrt{2\pi}\, u\, (\sigma_y + H/8)(H + 2\sigma_z)}$$

Assume a wind speed of 2.5 m/sec and stability class F. From Figures 4-4 and 4-5 obtain σ_y and σ_z values for the downwind distance in question. Plume rise (used to determine H) is computed as in Step 3 on page 4-8.

Step 10. The highest 1-hour concentration at the specified location (not accounting for contributions from other sources) is the larger of the concentration values estimated in Steps 8 and 9. To estimate concentrations for averaging times greater than one hour, take the 1-hour value estimated in Step 8 only, and then refer to the averaging time procedure described earlier (Step 5 on page 4-20). To account for contributions from other sources, see Section 4.5.2.

If the UNAMAP series of computer programs is available, Steps 1 through 8 above can be accomplished as follows:

1. Using the PTMAX program, obtain plume heights (H) for each wind speed-stability combination considered in Step 4 (and Step 5 if applicable).

2. Using the PTDIS program, estimate the maximum concentration at the specified distance for each wind speed-stability combination considered in (1). For the mixing height input to PTDIS, use plume height (H) for stabilities A-D (and for the E stability urban case) and use 5000 meters for stabilities E and F (rural).

3. For the highest 1-hour concentration at the specified location, use the largest value obtained in (2).

4.4 Annual Average Concentrations

This section presents procedures for estimating annual average ambient concentrations caused by a single point source. The procedure for estimating the annual concentration at a specified location is presented first, followed by a suggestion of how that procedure can be expanded to estimate the overall maximum annual concentration (regardless of location).

The procedures assume that the emissions are continuous and at a constant rate. The data required are emission rate, stack height, stack gas volume flow rate (or diameter and exit velocity), stack gas temperature, average afternoon mixing height, and a representative stability wind rose.* Refer to Sections 2 and 3 for a discussion of such data.

4.4.1 Annual Average Concentration at a Specified Location

Calculation procedure:

Step 1. (Applicable to stability categories A through D) Using the procedure described in Step 1 on page 4-7, obtain a normalized plume rise value ($u\Delta h$):

$$u\Delta h = 21.4\ F^{3/4} \text{ when } F < 55\ m^4/sec^3$$

$$u\Delta h = 38.7\ F^{3/5} \text{ when } F \geq 55\ m^4/sec^3$$

Step 2. (Applicable to stability categories E and F) Apply the following equation to estimate plume rise (Δh) as a function of wind speed. Apply the equation for both stable categories (E and F). Refer to Steps 1 and 3 on pages 4-7 and 4-8 for definition of terms in that equation:

*The stability wind rose is a joint frequency distribution of wind speed, wind direction and atmospheric stability for a given locality. Stability wind roses for many locations are available from the National Climatic Center, Asheville, North Carolina.

$$\Delta h = 2.4 \left[\frac{F \quad T_a}{ug \frac{\Delta\theta}{\Delta z}} \right]^{1/3}$$

Step 3. Compute plume rise (Δh) for each stability-wind speed category in Table 4-4 by (1) substituting the corresponding wind speed for u in the appropriate equation from Step 1 or 2 above and (2) solving the equation for Δh. The wind speeds listed in Table 4-4 are derived from the wind speed intervals used by the National Climatic Center (Table 4-5) in specifying stability-wind roses.

Step 4. Compute plume height (H) for each stability-wind speed category in Table 4-4 by adding the physical stack height (h_s) to each of the plume rise values computed in Step 3:

$$H = h_s + \Delta h$$

Step 5. Estimate the contribution to the annual average concentration at the specified location for each of the stability-wind speed categories in Table 4-4. First, determine the vertical dispersion coefficient (σ_z) for each stability class for the downwind distance (x) between the source and the specified location, using Figure 4-5. (Note: For urban F stability cases, use the σ_z for stability E.) Next, determine the mixing height (L) applicable to each stability class. For stabilities A to D, use the average afternoon mixing height for the area (Figure 4-16). For urban stabilities E and F, use the average morning

Table 4-4. STABILITY-WIND SPEED COMBINATIONS THAT ARE CONSIDERED IN ESTIMATING ANNUAL AVERAGE CONCENTRATIONS

Atmospheric Stability Categories	Wind Speed (m/sec)					
	1.5	2.5	4.5	7	9.5	12.5
A	*	*				
B	*	*	*			
C	*	*	*	*	*	
D	*	*	*	*	*	*
E	*	*	*			
F	*	*				

*It is only necessary to consider the stability-wind speed conditions marked with an asterisk.

Table 4-5. WIND SPEED INTERVALS USED BY THE NATIONAL CLIMATIC CENTER FOR JOINT FREQUENCY DISTRIBUTIONS OF WIND SPEED, WIND DIRECTION AND STABILITY

Class	Speed Interval, m/sec (knots)		Representative Wind Speed m/sec
1	0 to 1.8	(0 to 3)	1.5
2	1.8 to 3.3	(4 to 6)	2.5
3	3.3 to 5.4	(7 to 10)	4.5
4	5.4 to 8.5	(11 to 16)	7.0
5	8.5 to 11.0	(17 to 21)	9.5
6	>11.0	(>21)	12.5

mixing height (Figure 4-17). For <u>rural</u> stabilities E and F, mixing height is not applicable. Then, use that information as follows: For all stability-wind conditions when the plume height (H) is greater than (L), assume a zero contribution to the annual average concentration at the specified location. For each condition when $\sigma_z \leq 0.8L$, and for all <u>rural</u> stability E and F cases, apply the following equation[17] to estimate the contribution C (g/m^3):

$$C = \frac{2.03\ Q\ f}{\sigma_z\ u\ x}\ \exp\left[-\frac{1}{2}\left[\frac{H}{\sigma_z}\right]^2\right]$$

For each condition during which $\sigma_z > 0.8L$, the following equation[17] is applied:

$$C = \frac{2.55}{L}\ \frac{Q\ f}{u\ x}$$

In those equations:

Q = pollutant emission rate (g/sec)

u = wind speed (m/sec)

f = frequency of occurrence of the particular wind speed-stability combination (obtained from the stability-wind rose) for the wind direction of concern. Only consider the wind speed-stability combinations for the wind direction that will bring the plume closest to the specified location.

<u>Step 6</u>. Sum the contributions (C) computed in Step 5 to estimate the annual average concentration at the specified location.

4.4.2 <u>Maximum Annual Average Concentration</u>

To estimate the overall maximum annual average concentration (the maximum concentration regardless of location) follow the procedure for the annual average concentration at a specified location, repeating the procedure for each of several receptor distances, and for all directions. Because of the large number of calculations required, it is recommended that a computer model such as the CDM (Climatological Dispersion Model) be used. The CDM is a part of the UNAMAP series, which is discussed in Appendix A.

4.5 Special Topics

4.5.1 Concentrations at Receptors on Elevated Terrain

Dispersion models developed for estimating maximum ground-level concentrations in complex terrain have not been adequately evaluated. However, there is growing acceptance of the hypothesis that greater concentrations can occur on elevated than on flat terrain in the vicinity of an elevated source.* That is particularly true when the terrain extends well above the plume centerline (plume height).

A procedure is presented here to (1) determine whether or not an elevated plume may intercept terrain and, (2) if terrain is likely to be intercepted, estimate the maximum 24-hour concentration. The procedure is based largely upon the 24-hour mode of the EPA Valley Model[30]. A concentration estimate obtained through the procedure will likely be somewhat greater than provided by the Valley Model, primarily due to the relatively conservative plume height that is used in Step 1:

*An exception may be certain flat terrain situations where aerodynamic downwash is a problem. (See Procedure 4(f) on page 4-18).

Step 1. Determine if the plume is likely to intercept terrain in the vicinity of the source:

(1) Compute one-half the plume rise ($\Delta h/2$) that can be expected during F stability and a wind speed (u) of 2.5 m/sec. (The reason for using only one-half the normally computed plume rise is to provide a margin of safety in determining (1) if the plume may intercept terrain and (2) the resulting ground-level concentration.):

$$\Delta h/2 = 1.2\left[\frac{F\ T_a}{ug\ \frac{\Delta\theta}{\Delta z}}\right]^{1/3}$$

Refer to Steps 1 and 3 on pages 4-7 and 4-8 for definition of terms.

(2) Compute a conservative plume height (H_c) by adding the physical stack height (h_s) to $\Delta h/2$:

$$H_c = h_s + \Delta h/2$$

(3) Determine if any terrain features in the vicinity of the source are as high as H_c. If so, proceed with Step 2. If that is not the case, the plume is not likely to intercept terrain, and Step 2 is not applicable.*

*Even if the plume is not likely to intercept terrain (and for all concentration averaging times of concern) the user should attempt to account for terrain if the terrain features are significant. A procedure for doing so is to reduce the computed plume height H (for all stabilities) by the elevation difference between stack base and location of the receptor(s) in question. The adjusted plume heights can then be used in conjunction with the "flat-terrain" modeling procedures described earlier.

Step 2. Estimate the maximum 24-hour ground-level concentration on elevated terrain in the vicinity of the source:

(1) Using a topographic map, determine the distance from the source to the nearest ground-level location at the height H_c.

(2) Using Figure 4-18 and the distance determined in (a), estimate a 24-hour χ/Q value.

(3) Multiply the $(\chi/Q)_{24}$ value by the emission rate Q (g/sec) to estimate the maximum 24-hour concentration χ_{24} due to plume interception of terrain:

$$\chi_{24} = (\chi/Q)_{24} \, (Q)$$

4.5.2 Contributions from Other Sources

To assess the significance of the air quality impact of a proposed source, the impact of nearby sources and "background" must be specifically determined. (Background includes those concentrations due to natural sources and distant, unspecified man-made sources.) Then the impact of the proposed source can be separately estimated, applying the techniques presented elsewhere in Section 4, and superimposed upon the impact of the nearby sources and background to determine total concentrations in the vicinity of the proposed source.

This section addresses the estimation of concentrations due to nearby sources and background. Three situations are considered:

A. A proposed source relatively isolated from other sources.

B. A proposed source in the vicinity of a few other sources.

C. A proposed source in the vicinity of an urban area or other large number of sources.

It must be noted that in all references to air quality monitoring in the following discussion, it is assumed that the source in question is not yet operating. If the source is emitting pollutants during the period of air quality data collection, care must be taken not to use monitoring data influenced by the impact of the source.

A. Relatively Isolated Proposed Source

A proposed source may be considered to be isolated if it is expected that background will be the only other significant contributor to ambient pollutant concentrations in its vicinity. In that case, it is recommended that air quality data from monitors in the vicinity of the proposed source be used to estimate the background concentrations. If monitoring data are not available from the vicinity of the source, use data from a "regional" site; i.e., a site that characterizes air quality across a broad area, including that in which the source is located.

Annual average concentrations should be relatively easy to determine from available air quality data. For averaging times of about 24 hours or less, meteorology must be accounted for; i.e., it is necessary to ensure that background concentration estimates are based on data collected during the same meteorological situations as those during which the source is expected to have its greatest impact on air quality.

B. Proposed Source in the Vicinity of a Few Other Sources

If there already are a few sources in the vicinity of the proposed facility, the air quality impact of these sources should be accounted for.

As long as the number of nearby sources is relatively small, the recommended procedure is to use (1) air quality monitoring data to estimate background concentrations and (2) dispersion modeling to estimate concentrations due to the nearby sources. Then superimpose those estimates to determine total concentrations in the vicinity of the proposed source.

To estimate background concentrations, follow the same basic procedure as in the case of an isolated source. In this case, however, there is one added complication. Wind direction must be accounted for in order to single out the air quality data that represent background only (i.e., data that are not affected by contributions from nearby sources).

Concentrations due to the nearby sources will normally be best determined through dispersion modeling. The modeling techniques presented in this guideline may be used. If the user has access to UNAMAP (see Appendix A and references to UNAMAP in Section 4), the modeling effort can be considerably simplified. If UNAMAP can not be used, the user should model each source separately to estimate concentrations due to each source during various meteorological conditions and at an array of receptor locations (e.g., see Sections 4.3 and 4.4.1) where interactions between the effluents of the proposed source and the nearby sources can occur. Significant locations include (1) the area of expected maximum impact of the proposed source, (2) the area of maximum impact of the nearby sources, and (3) the area where all sources will combine to cause maximum impact. It may be necessary to identify those locations through a trial and error analysis.

C. <u>Proposed Source in the Vicinity of an Urban Area or Other Large Number of Sources</u>

For more than a very small number of nearby sources, it may be impractical to model each source separately. Two possible alternatives for estimating ambient concentrations are to use air quality monitor data or a multi-source dispersion model.

If data from a comprehensive air monitoring network are available, it may be possible to rely entirely on the measured data. The data should be adequate to permit a reliable assessment of maximum concentrations, particularly in (1) the area of expected maximum impact of the proposed source, (2) the area of maximum impact of the existing sources and (3) the area where all sources will combine to cause maximum impact.

In some cases, the available air quality monitor data will only be adequate to estimate general area-wide background concentrations. In such cases, there is no choice but to use dispersion modeling to estimate concentrations due to the nearby sources. If possible, a multi-source dispersion model should be used. If the user has access to UNAMAP (see Appendix A and references to UNAMAP in Section 4) the Climatological Dispersion Model (CDM) can be applied for long-term concentration estimates and the PTMTP model for short-term estimates (PTMTP can handle up to 25 point sources).

If it is not feasible to apply a multi-source model, and there is a considerable number of nearby sources, a rough estimate of maximum concentrations due to those sources can be made by arbitrarily grouping the sources into an area source through the following equation[31]. (The estimate is primarily applicable to receptor locations near the center of the area source, defined below, although it may be considered a reasonable first-approximation for any location within the area.):

$$C = 18 \frac{Q}{u} (\Delta x)^{1/4}$$

where:

C = maximum contribution to ground-level concentrations (g/m^3)

Q = average emission rate ($g/m^2/sec$) within the area defined by Δx

u = assumed average wind speed (m/sec) for the averaging time of concern

Δx = length (m) of one side of the smallest square area that will contain the nearby sources, ignoring relatively small outlying sources or any source that is considerably removed from the other sources.

The best results will be obtained with the above equation when emissions are uniformly distributed over the defined area. Any large point sources in the vicinity should be modeled separately, and the estimated concentrations manually superimposed upon that computed for the area source.

4.5.3 Long Range Transport

In certain instances it will be necessary to estimate the air quality impact of a proposed source at locations beyond its vicinity (beyond roughly 30-50 kilometers). To estimate seasonal or annual average concentrations (out to about 100 kilometers) the procedures of Section 4.4 will provide a rough estimate. Those procedures should not be applied beyond 100 kilometers.

For short-term estimates (concentration averaging times up to about 24 hours) beyond the vicinity of the source and out to 100 kilometers downwind, the following procedure is recommended. The procedure accounts for the meteorological situations likely to result in the highest concentrations at large distances; viz., limited mixing conditions (Steps 1-5) and stable conditions (Steps 6-9):

Step 1. Estimate the normalized plume rise ($u\Delta h$) applicable to neutral and unstable atmospheric conditions. Use the procedure described in Step 1 on page 4-7.

Step 2. Compute plume height (H):

$$H = h_s + \frac{u\Delta h}{7.5}$$

Step 3. Using Figure 4-19, obtain a $\chi u/Q$ value for the desired downwind distance (D stability case).

Step 4. Compute the maximum 1-hour D stability concentration χ_{max}, using the $\chi u/Q$ value obtained in Step 3:

$$\chi_{max} = \frac{Q}{7.5} [\chi u/Q]$$

For Q, substitute the source emission rate (g/sec). The value 7.5 is the recommended wind speed (m/sec) for computations of χ_{max} at large distances under limited mixing conditions.

Step 5. Estimate the plume rise (Δh) applicable to stable conditions (stability class E), using the procedure described in Step 3 on page 4-8. Assume a wind speed equal to 4 m/sec.

Step 6. Compute plume height (H):

$$H = h_s + \Delta h$$

Step 7. From Figure 4-20, obtain a $\chi u/Q$ value for the same distance considered in Step 3 above.

Step 8. Compute the maximum 1-hour E stability concentration χ_{max}, using the $\chi u/Q$ value obtained in Step 7:

$$\chi_{max} = \frac{Q}{4} [\chi u/Q]$$

where 4 is the assumed wind speed (m/sec).

Step 9. Select the higher of the χ_{max} values computed in Steps 4 and 8. The selected value represents the highest 1-hour concentration likely to occur at the specified distance.

Step 10. To estimate concentrations for averaging times up to 24 hours, multiply the 1-hour value by the factors presented in Step 5 on page 4-20.

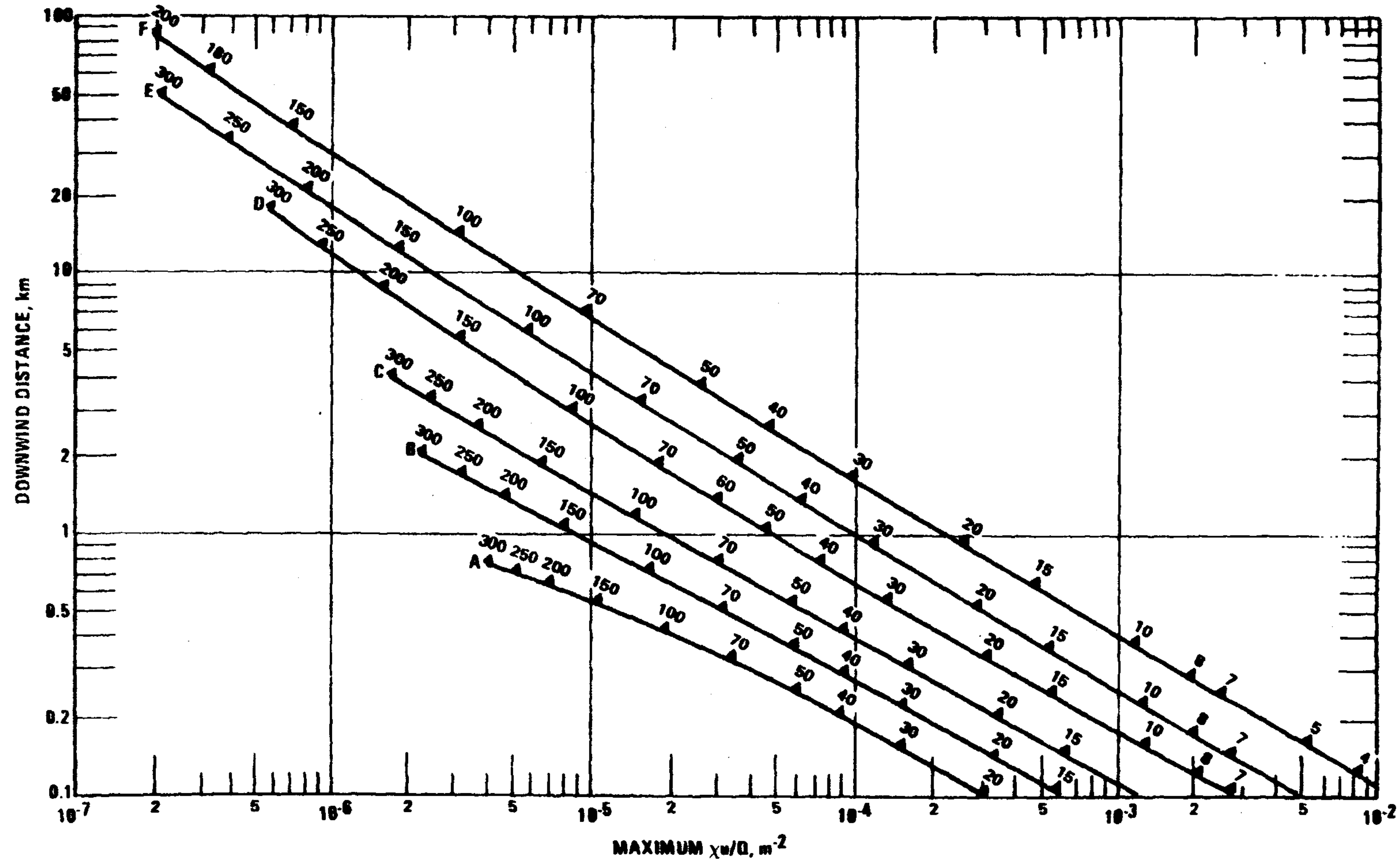

Figure 4-2. Downwind distance to maximum concentration and maximum $\chi u/Q$ as a function of stability class for rural terrain.[17] Plume heights (m) are on the curves.

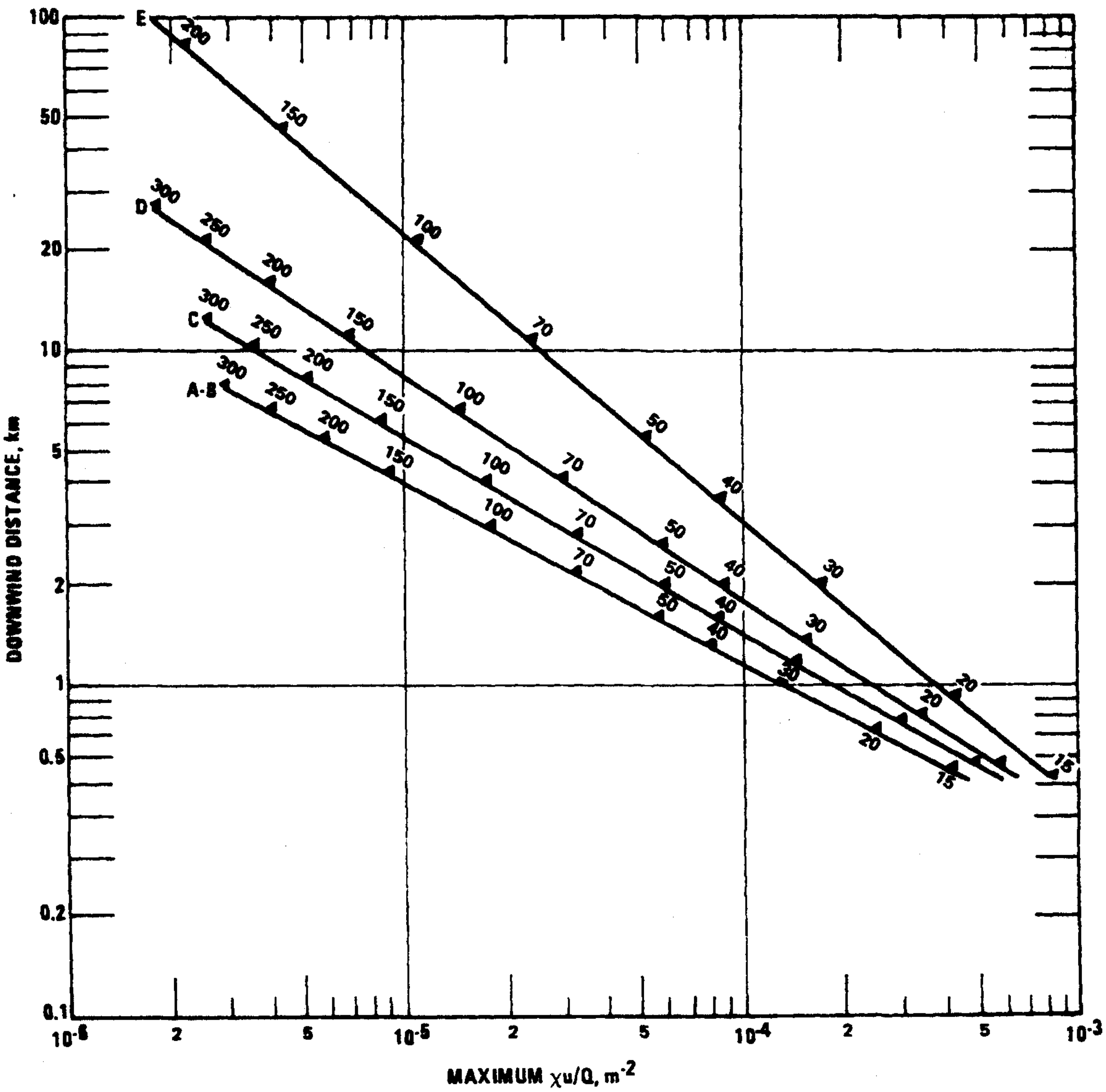

Figure 4-3. Downwind distance to maximum concentration and maximum $\chi u/Q$ as a function of stability class for urban terrain.[1,32] Plume heights (m) are on the curves.

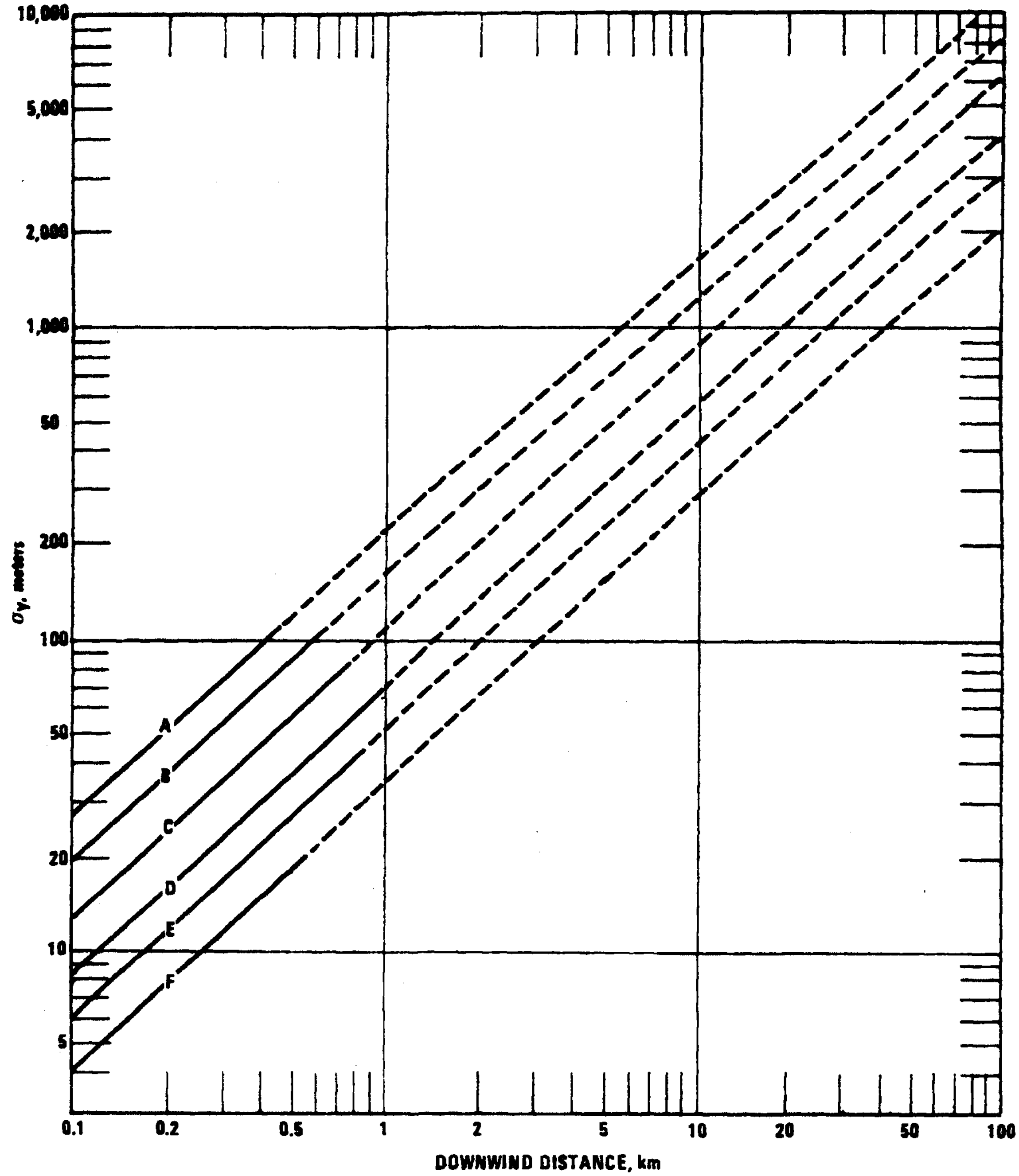

Figure 4-4. Horizontal dispersion parameter (σ_y) as a function of downwind distance and stability class; rural terrain.[17]

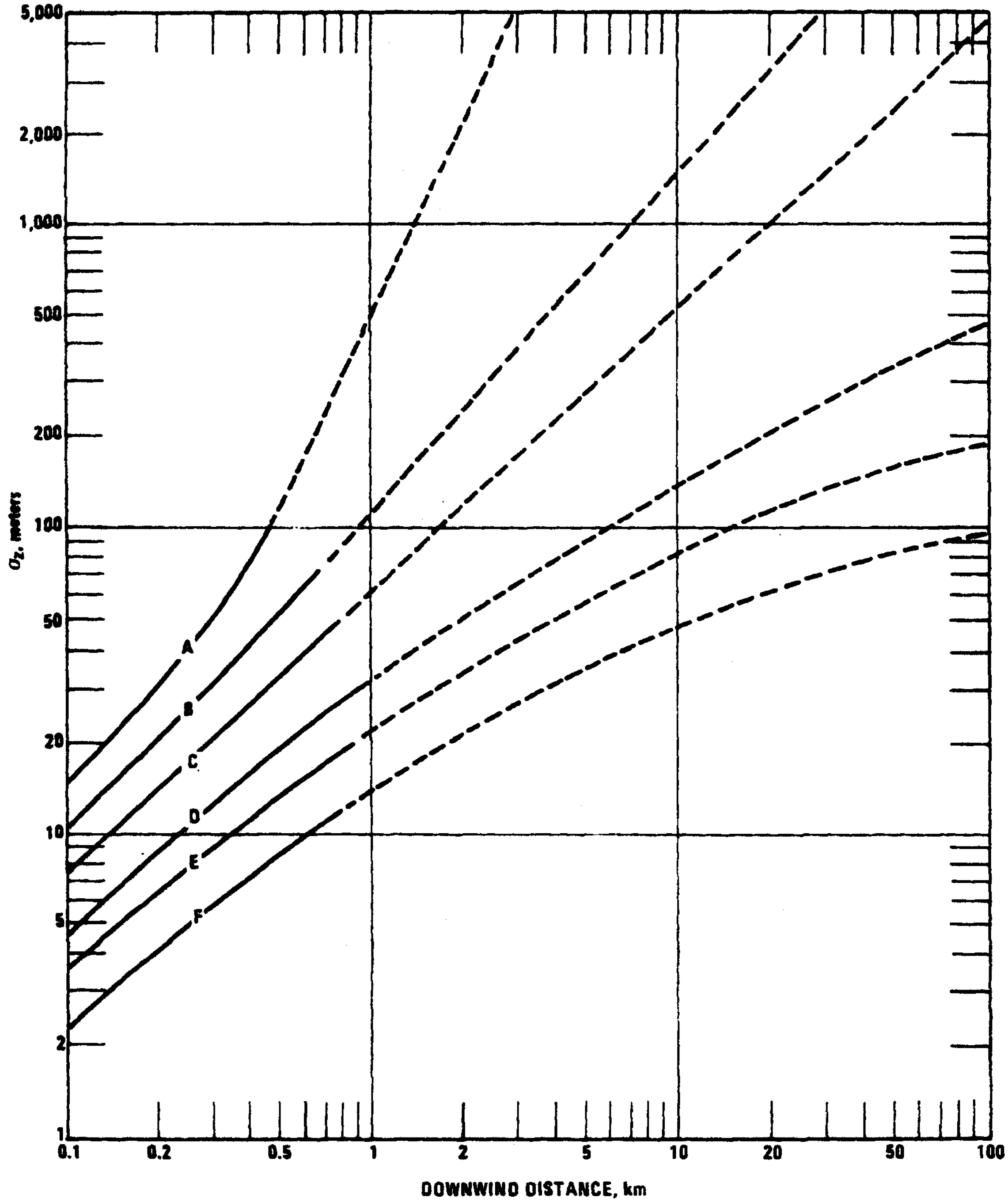

Figure 4-5. Vertical dispersion parameter (σ_z) as a function of downwind distance and stability class; rural terrain.[17]

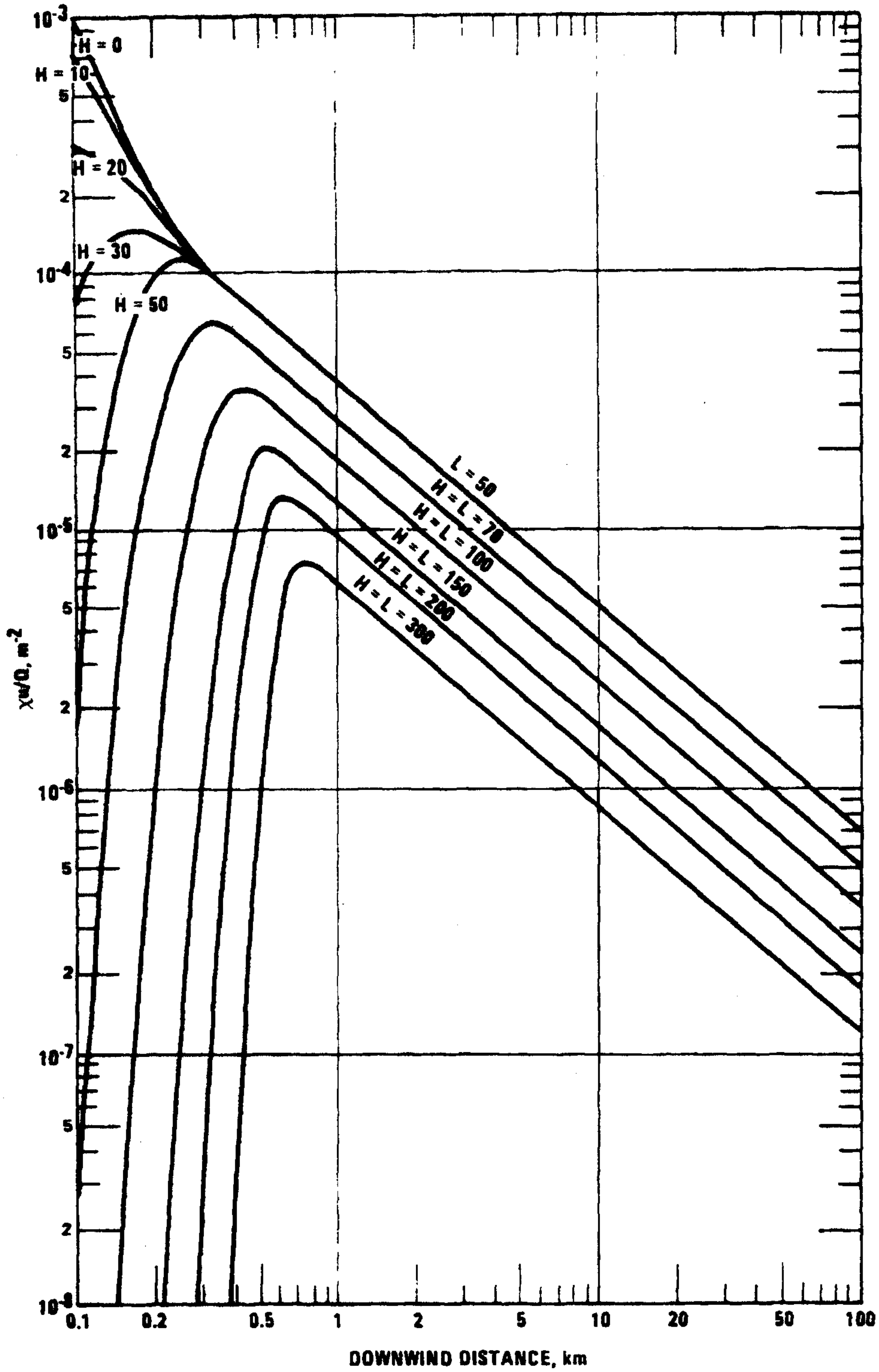

Figure 4-6. Stability class A; rural terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leqslant$ 50 m; L = H for H > 50 m.

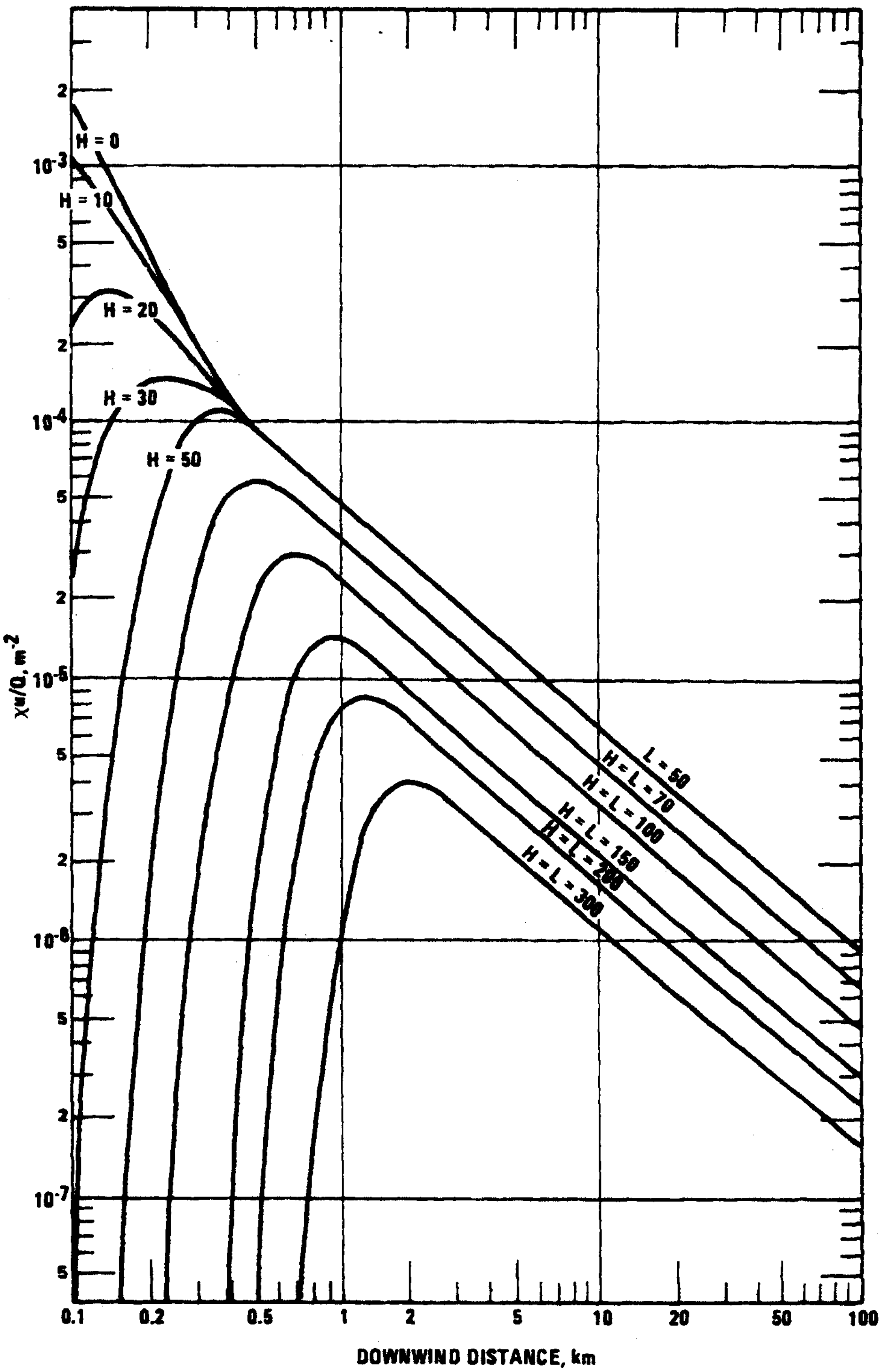

Figure 4-7. Stability class B; rural terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leqslant$ 50 m; L = H for H > 50 m.

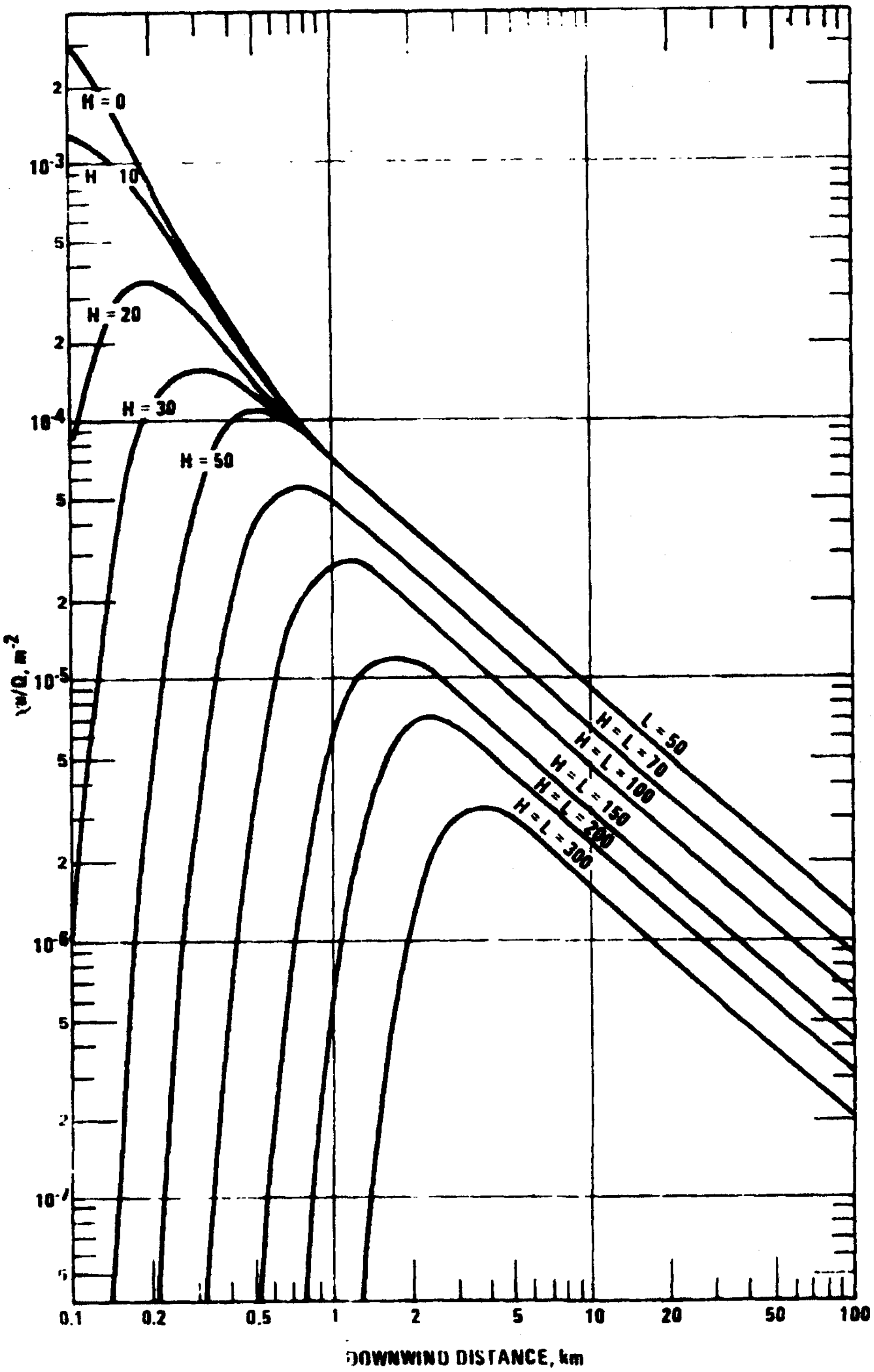

Figure 4 8. Stability class C, rural terrain χu/Q versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L 50 m for H ≤ 50 m, L H for H 50 m

A-47

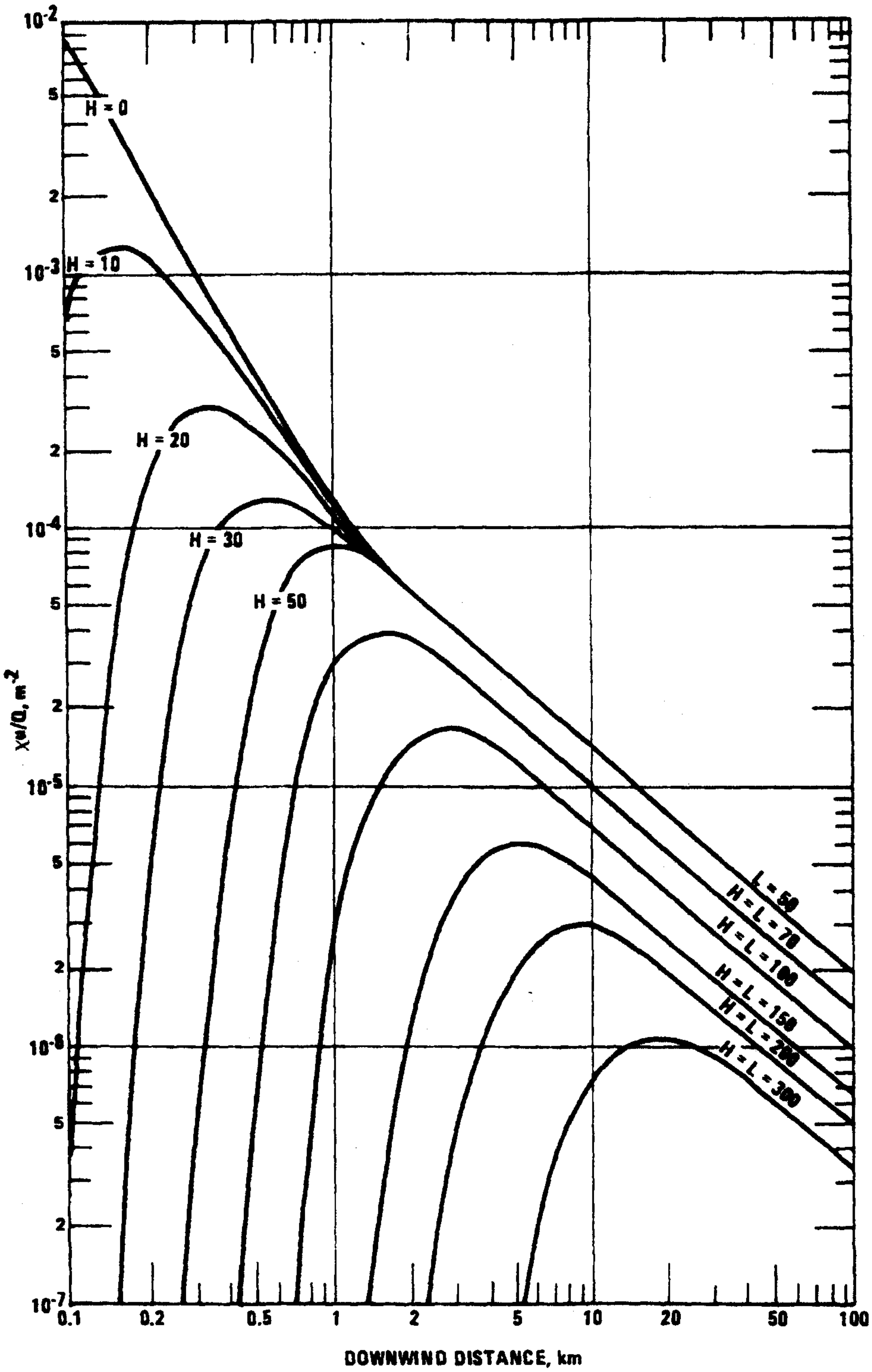

Figure 4-9. Stability class D; rural terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leqslant$ 50 m; L = H for H $>$ 50 m.

4-48

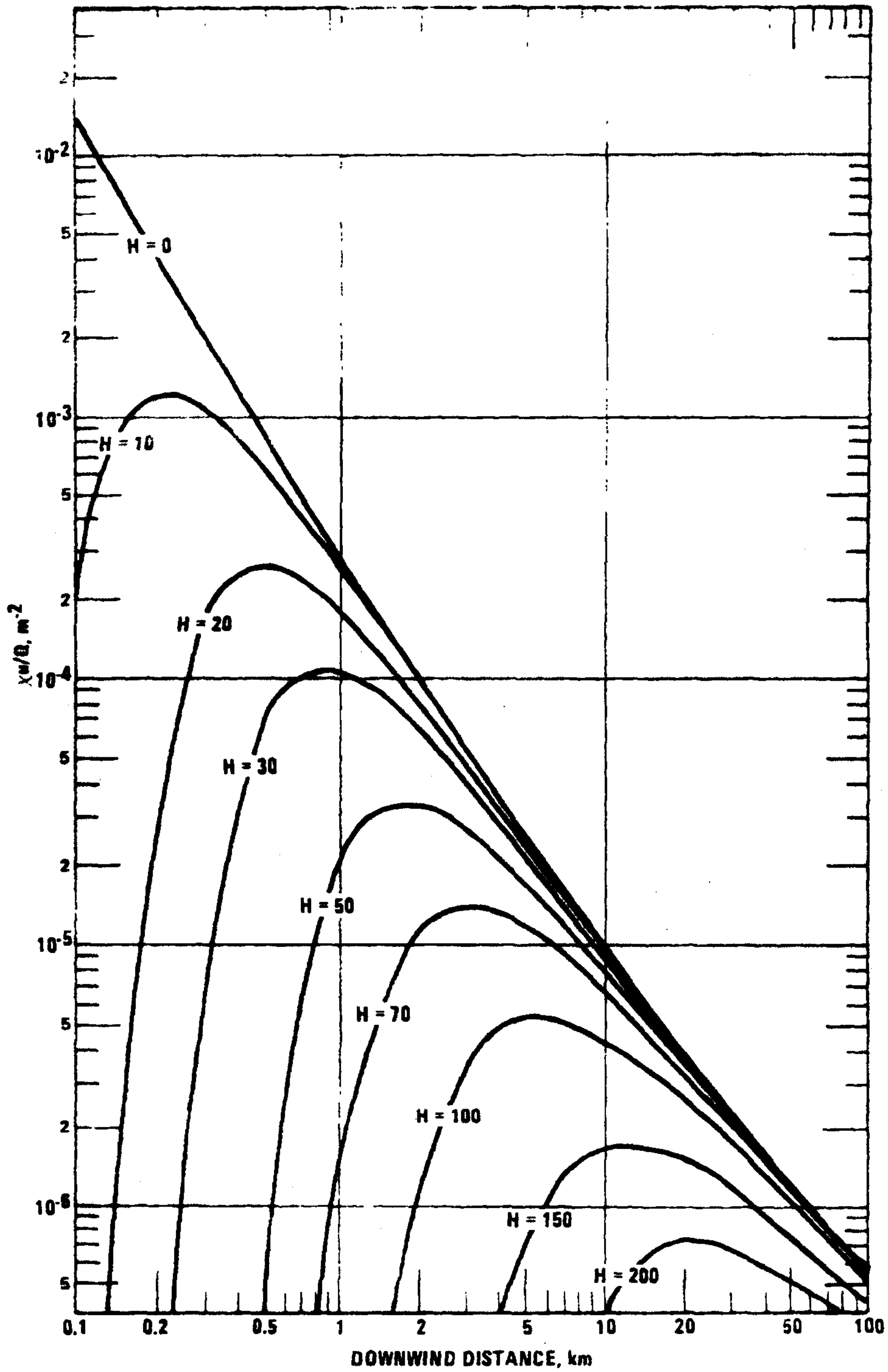

Figure 4-10. Stability class E; rural terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leqslant$ 50 m, L = H for H > 50 m.

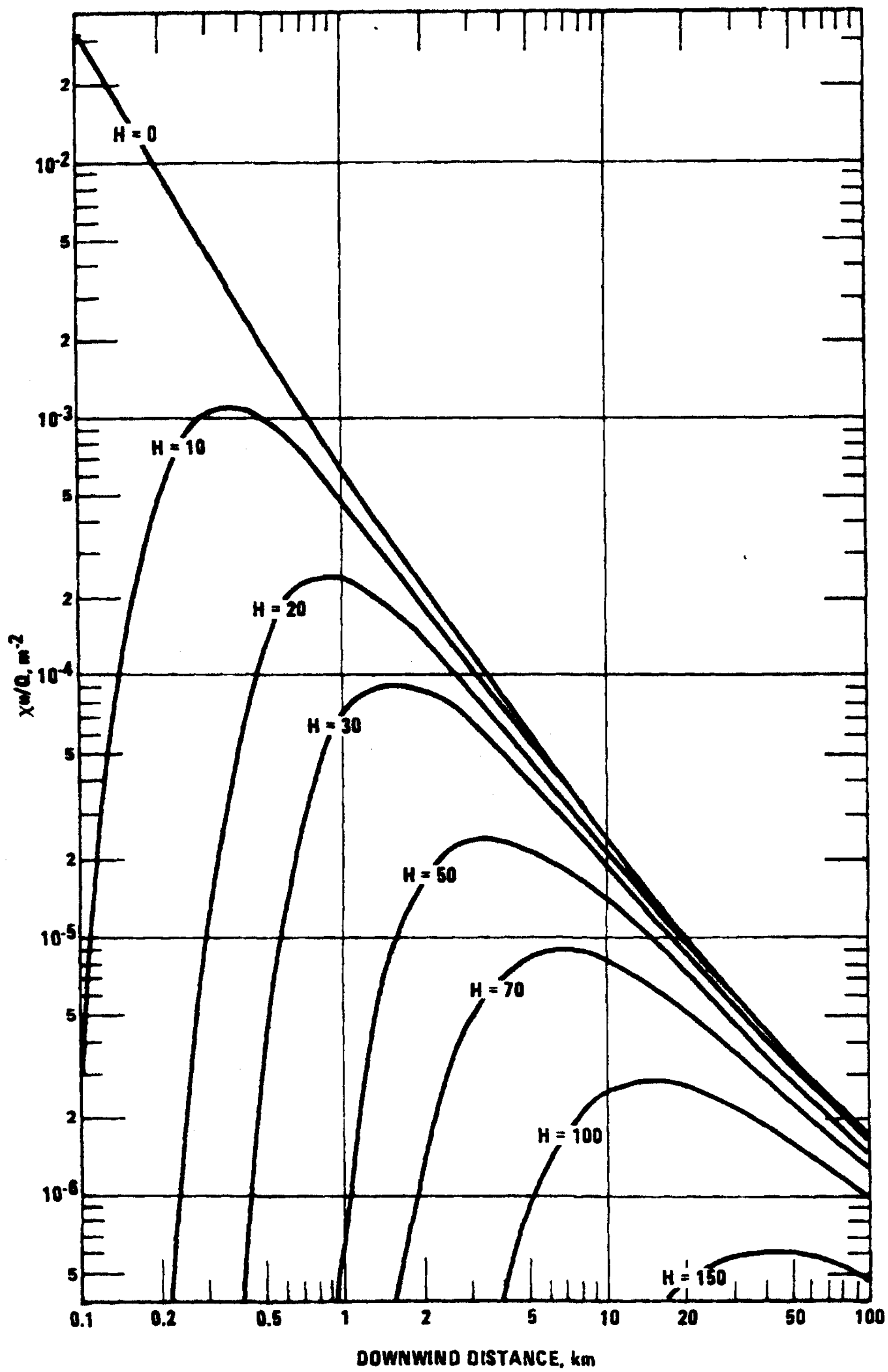

Figure 4-11. Stability class F; rural terrain χu/Q versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ≤ 50 m; L = H for H > 50 m.

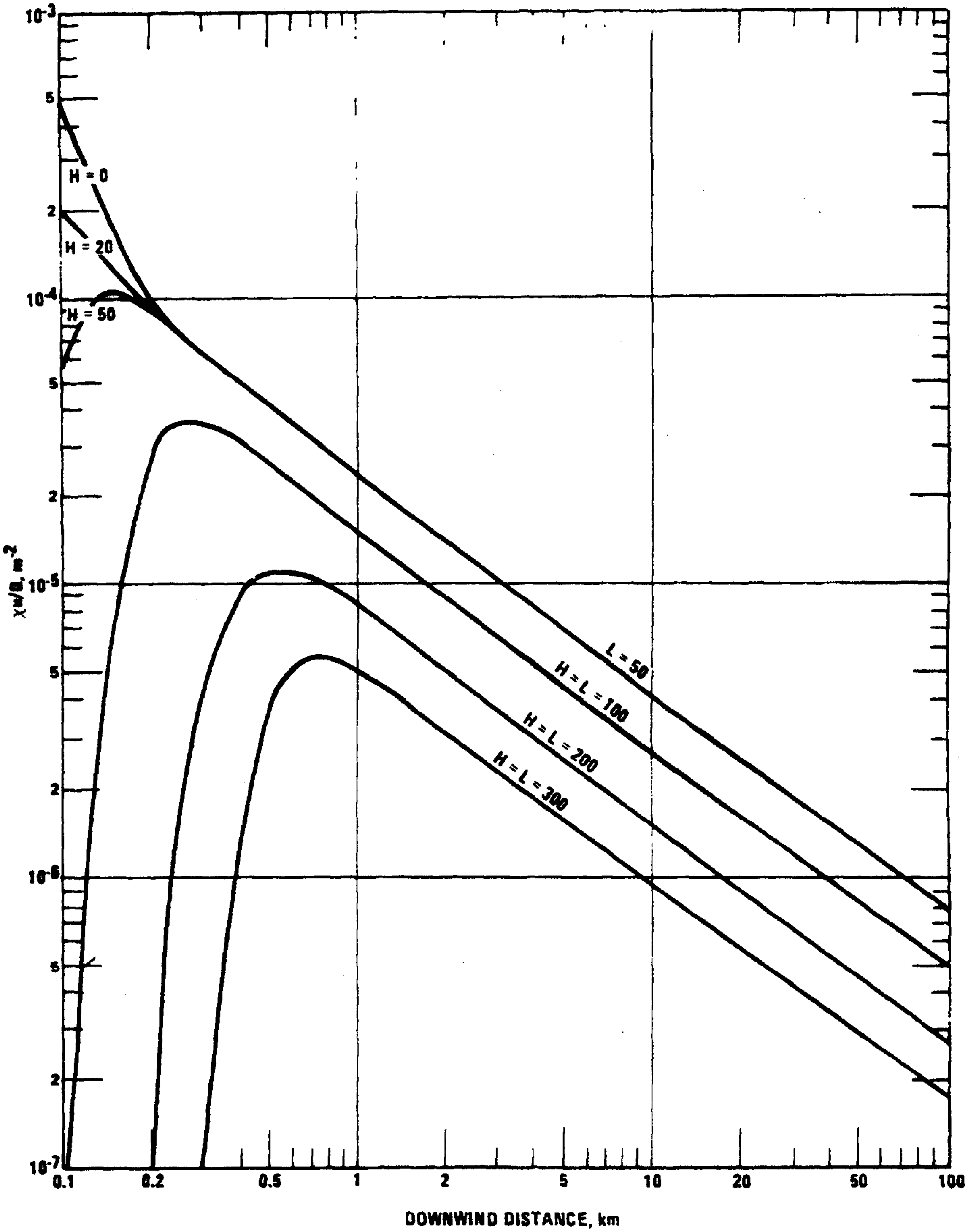

Figure 4-12. Stability classes A and B; urban terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leqslant$ 50 m; L = H for H > 50 m.[32]

4-51

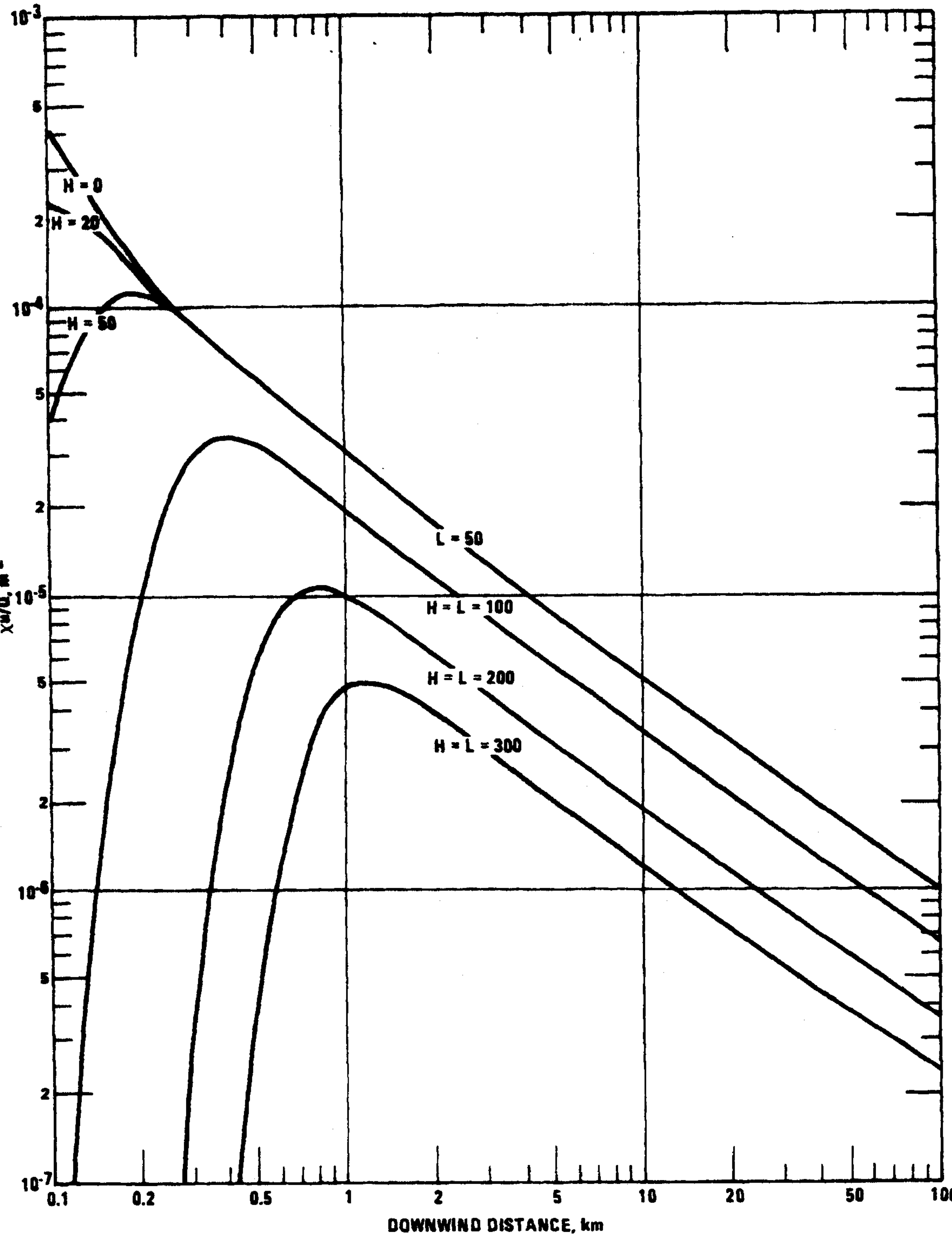

Figure 4-13. Stability class C; urban terrain χu/Q versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ≤ 50 m; L = H for H > 50 m.[32]

4-52

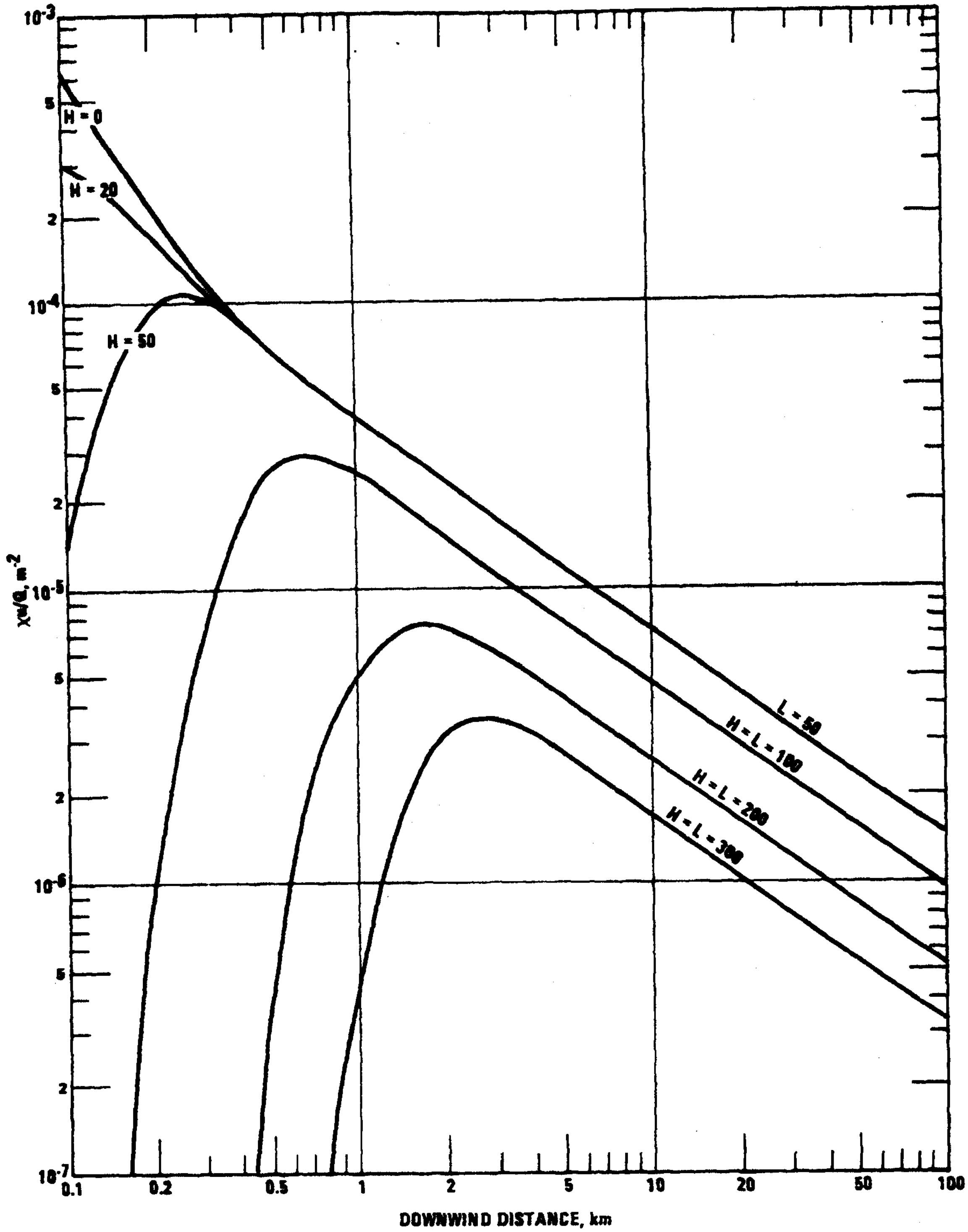

Figure 4-14. Stability class D; urban terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leqslant$ 50 m; L = H for H > 50 m.[32]

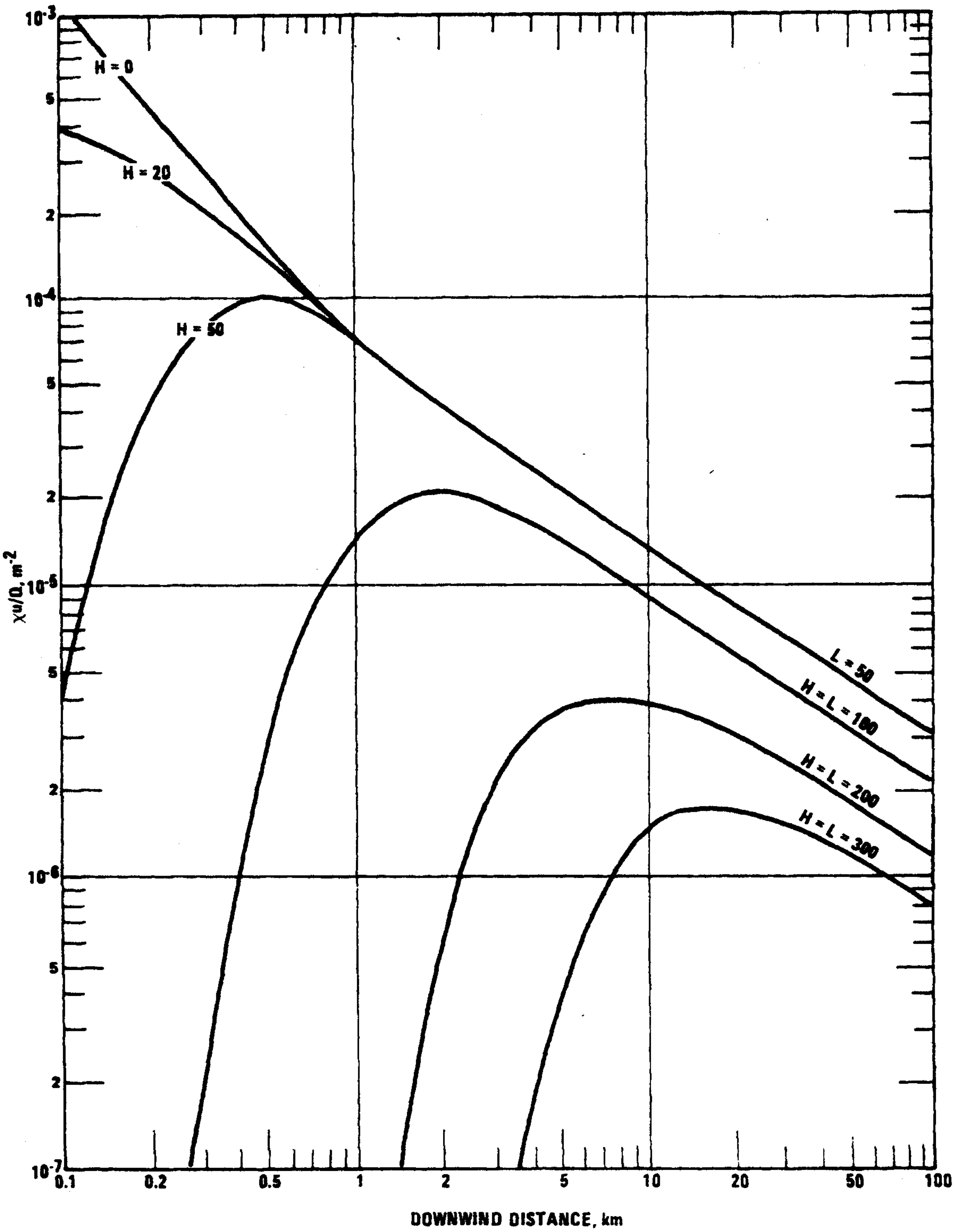

Figure 4-15. Stability class E; urban terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leqslant$ 50 m; L = H for H $>$ 50 m.[32]

4-54

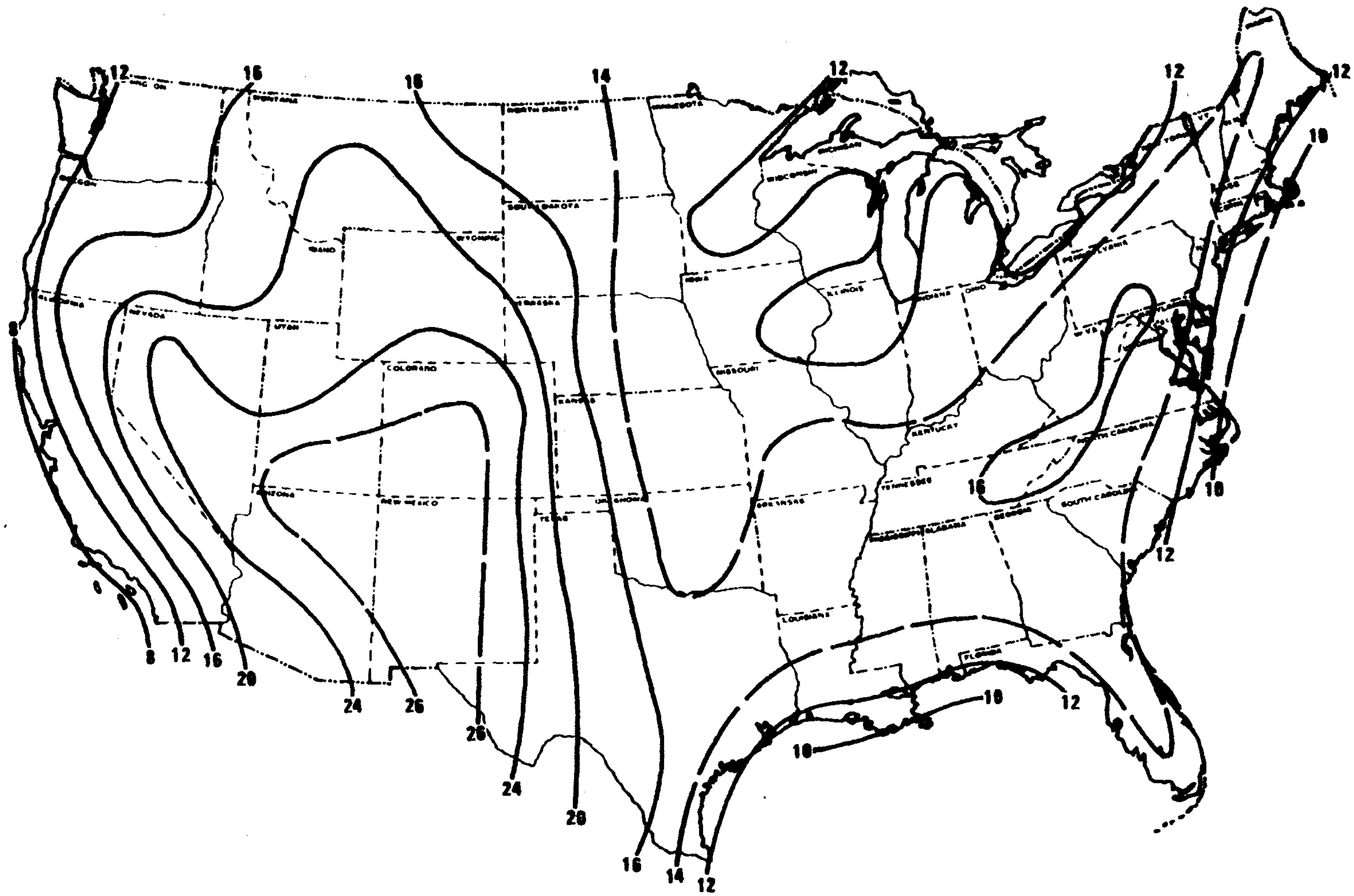

Figure 4-16. Isopleths (hundreds of meters) of mean annual afternoon mixing heights[19].

4-55

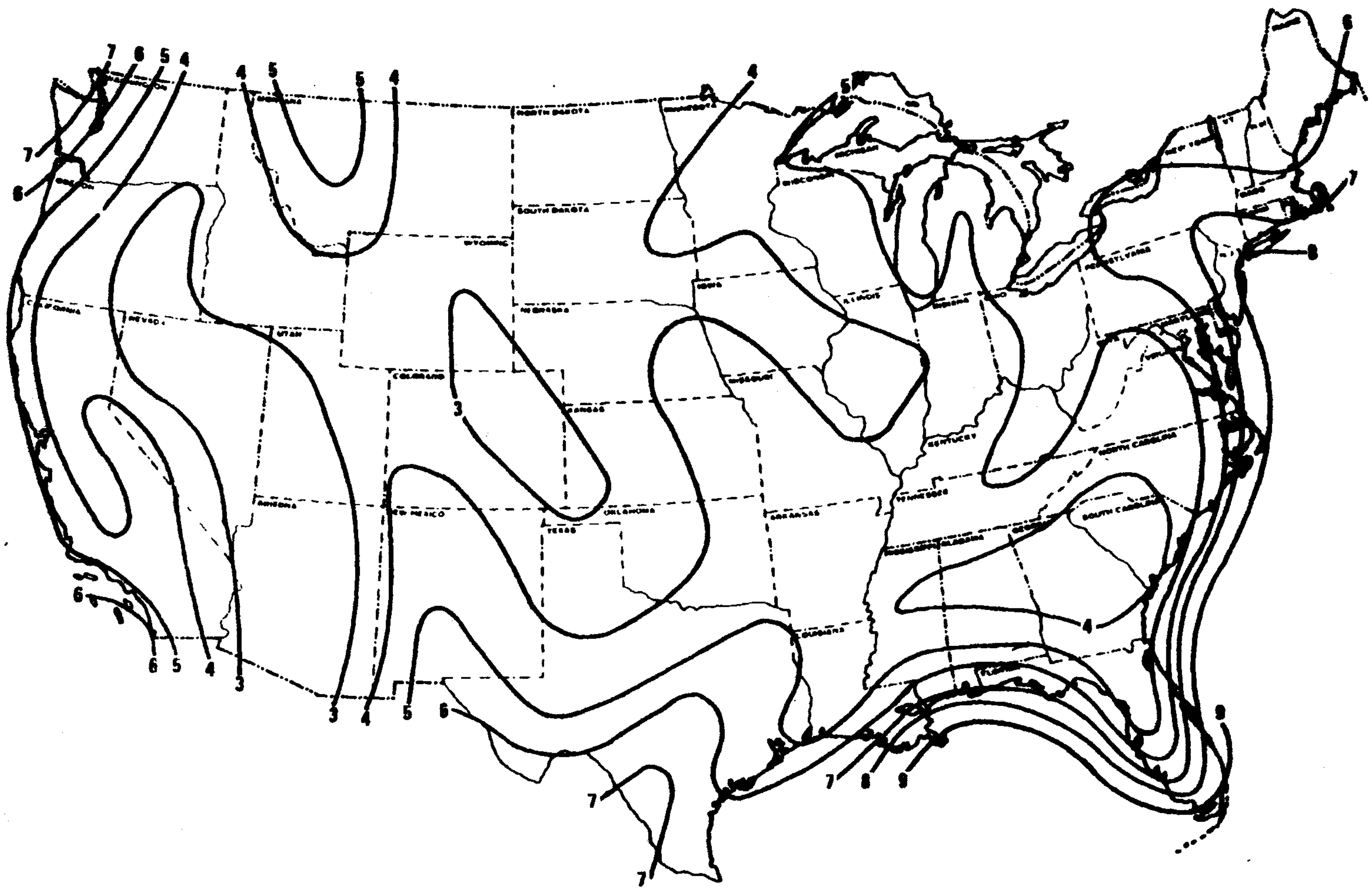

Figure 4-17. Isopleths (hundreds of meters) of mean annual morning mixing heights[19].

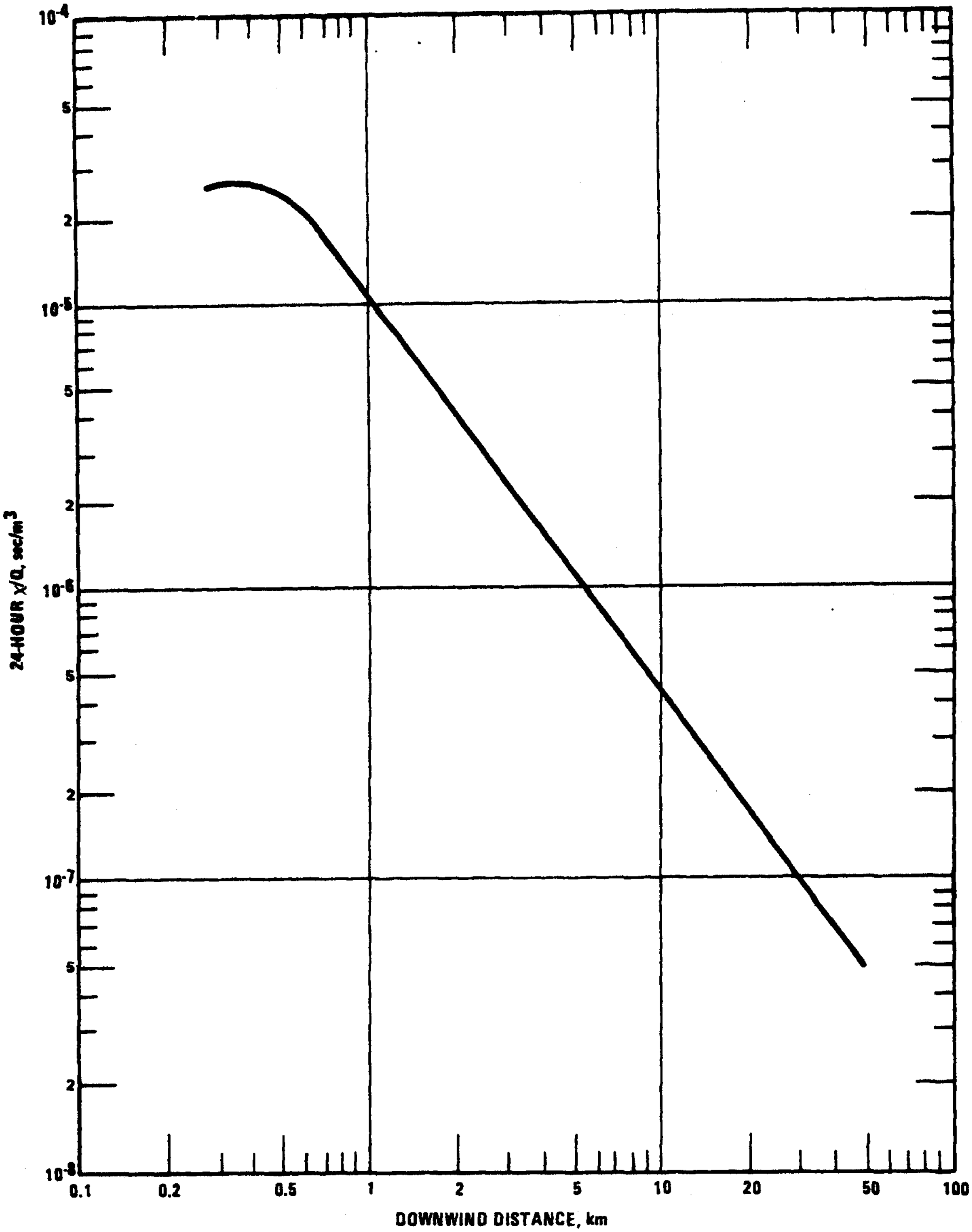

Figure 4-18. 24-hour χ/Q versus downwind distance, obtained from the Valley Model[30]. Assumptions include stability class F, a wind speed of 2.5 m/sec, and plume height 10 meters above terrain.

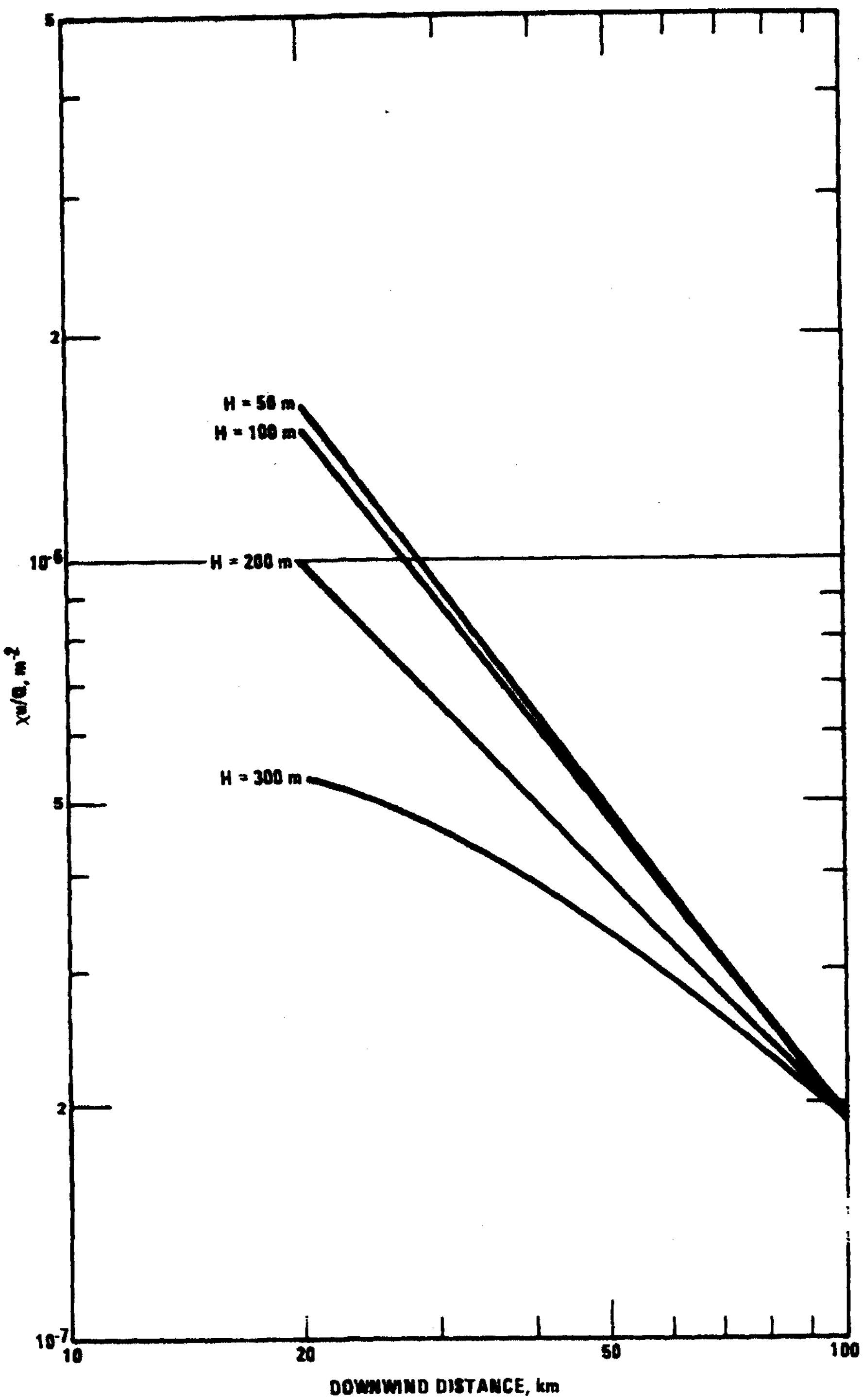

Figure 4-19. Maximum $\chi u/Q$ as a function of downwind distance and plume height (H), assuming a mixing height of 500 meters; D stability.

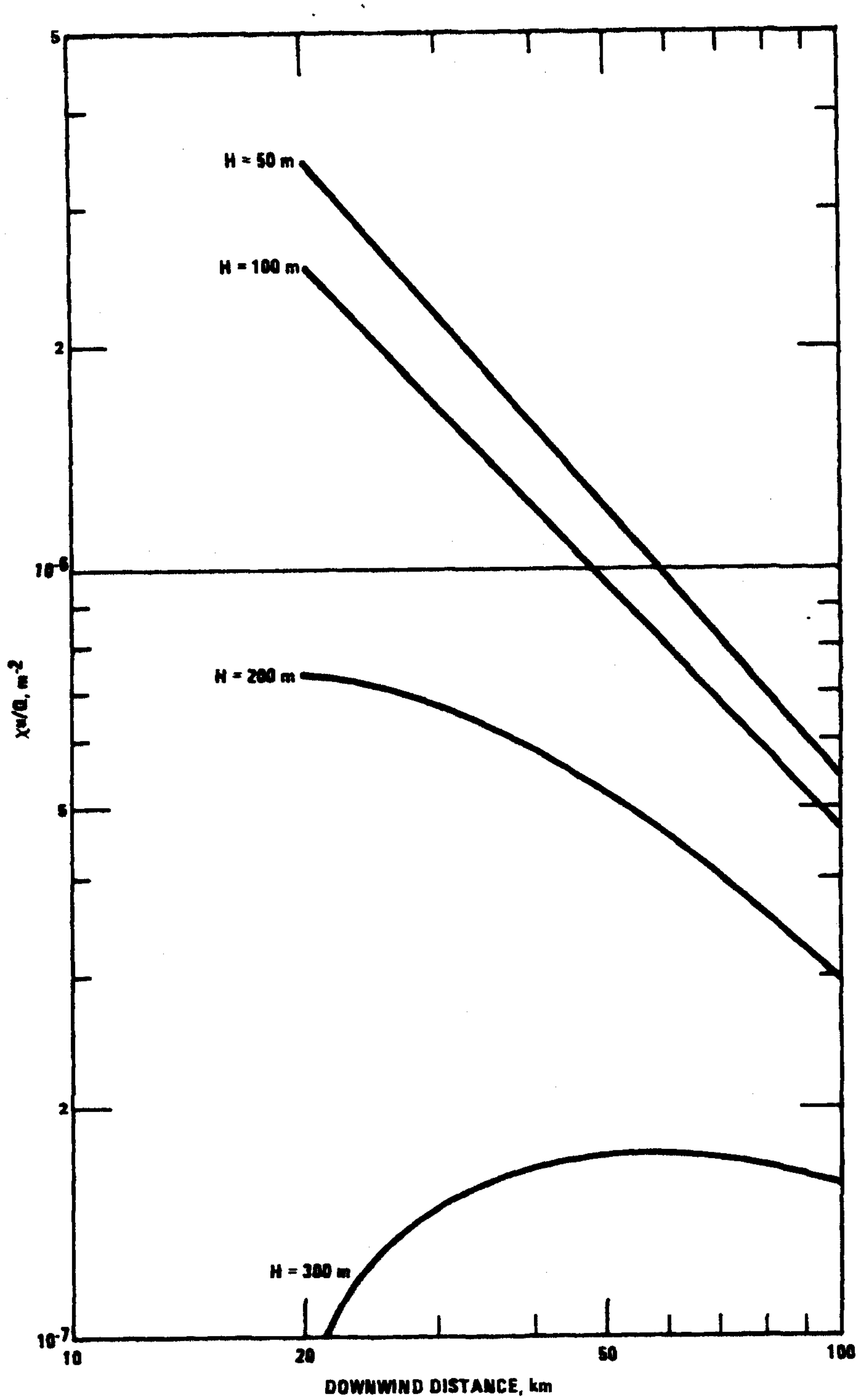

Figure 4-20. Maximum χu/Q as a function of downwind distance and plume height (H); E stability.

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APPENDIX A

UNAMAP DISPERSION MODELS

Since May 1973 the Meteorology and Assessment Division, Environmental Protection Agency, Research Triangle Park, North Carolina, has made six air quality simulation models available to those wanting to make dispersion estimates. These six models are collectively referred to as UNAMAP (Users' Network for Applied Modeling of Air Pollution). Brief abstracts of the six models are enclosed. Publications related to these models are listed on the enclosed UNAMAP Reference sheet. Most of these publications are available from NTIS.

In addition to making these models available to EPA users on the UNIVAC 1110 in Research Triangle Park, the UNAMAP models are available in two ways:

(1) The UNAMAP models can be executed on Computer Science Corporation's INFONET. Users must establish accounts with CSC and are charged according to the services provided. Users are linked to the computer via telephone lines. Users interested in access to UNAMAP by this method should contact the INFONET Customer Service Representative at the nearest Computer Sciences Corporation Office. The principal advantage of accessing UNAMAP in this way is relatively rapid access to changes or additions to UNAMAP. CSC is making some changes to the operation of UNAMAP on INFONET in order to ensure that updates reach each customer quickly.

(2) The UNAMAP models are available on magnetic tape from NTIS. The tape record mode is 9 track, 800 bits per inch, EBCDIC code, odd parity. Physical records each contain 10 logical records in card image format (that is, 80 byte logical records; 800 byte block size). As an

option NTIS can copy the tape to 7 track (556 or 800 bpi) BCD format. The price per tape is $175.00 ($219.00 - foreign orders). When ordering, specify the desired format as mentioned above. The tape identification should be specified as follows:

NTIS Accession No. PB 229-771, Users Network for Applied Modeling of Air Pollution (UNAMAP)

Until January 1975, the first version of this tape containing interactive versions of the six UNAMAP models was sold. In January 1975, this original tape was replaced with version 2 of this tape. The new tape contains batch versions and test data for all six models and interactive versions of PTMAX, PTDIS, PTMTP, and HIWAY. The principal reason for the change was the availability of a new version of HIWAY. Persons ordering PB 229-771 after about February 1, 1975, should have received version 2. If your tape is version 2 you will have version 74333 in your HIWAY program source listing. For purchasers of the version 1 tape, a 'Change Tape for UNAMAP', PB 240-273 is available for $97.50 ($122.50-foreign orders). A list of purchasers of the tape that fill in the registration form accompanying the tape is maintained, so that additional information can be furnished to them.

UNAMAP MODEL ABSTRACTS

APRAC Stanford Research Institute's urban carbon monoxide model. Computes hourly averages for any urban location. Requires an extensive traffic inventory for the city of interest. Requirements and technical details are documented in "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program" which is available from NTIS (accession number PB 213-091, $5.25).

HIWAY An interactive program which computes the hourly concentrations of non-reactive pollutants downwind of roadways. It is applicable for uniform wind conditions and level terrain. Although best suited for at-grade highways, it can also be applied to depressed highways (cut sections). The "User's Guide for HIWAY: A Highway Air Pollution Model," is available from EPA as EPA-650/4-74-008 and from NTIS (accession number PB 239-944/AS, $4.25).

CDM The Climatological Dispersion Model determines long term (seasonal or annual) quasi-stable pollutant concentrations at any ground level receptor using average emission rates from point and area sources and a joint frequency distribution of wind direction, wind speed, and stability for the same period. The "User's Guide for the Climatological Dispersion Model" is available from EPA as EPA-R4-73-024 and from NTIS (accession number PB 227-346-AS, $4.75).

Three Point Source Models - The three following point source models use Briggs plume rise methods and Pasquill-Gifford dispersion methods as given in EPA's AP-26, "Workbook of Atmospheric Dispersion Estimates," to estimate hourly concentrations for stable pollutants. A draft users' guide for these three models is available from the Environmental Applications Branch, Meteorology and Assessment Division, Mail Drop 80, EPA, Research Triangle Park, N.C. 27711.

PTMAX An interactive program that performs an analysis of the maximum short term concentrations from a single point source as a function of stability and wind speed. The final plume height is used for each computation.

PTDIS An interactive program that estimates short-term concentrations directly downwind of a point source at distances specified by the user. The effect of limiting vertical dispersion by a mixing height can be included and gradual plume rise to the point of final rise is also considered. An option allows the calculation of isopleth half-widths for specific concentrations at each downwind distance.

PTMTP An interactive program that estimates for a number of arbitrarily located receptor points at or above ground-level, the concentration from a number of point sources. Plume rise is determined for each source. Downwind and crosswind distances are determined for each source-receptor pair. Concentrations at a receptor from various sources are assumed additive. Hourly meteorological data are used; both hourly concentrations and averages over any averaging time from one to 24 hours can be obtained.

UNAMAP MODEL REFERENCES

APRAC User's Manual for the APRAC-1A Urban Diffusion Model Computer Program (available from NTIS, accession number PB 213-091. $5.25 per paper copy, $2.25 for microfiche.) [Additional information is available on APRAC from:

A Practical, Multipurpose Urban Diffusion Model for Carbon Monoxide (NTIS accession number PB 196-003)

Field Study for Initial Evaluation of an Urban Diffusion Model for Carbon Monoxide (NTIS accession number PB 203-469)

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1. REPORT NO. EPA-450/4-77-001	2.
	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Guidelines for Air Quality Maintenance Planning and Analysis--Volume 10 (Revised): Procedures for Evaluating Air Quality Impact of New Stationary Sources	5. REPORT DATE October 1977
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Laurence J. Budney	8. PERFORMING ORGANIZATION REPORT NO. OAQPS No. 1.2-029 R
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air and Waste Management Office of Air Quality Planning and Standards Research Triangle Park, NC 27711	10. PROGRAM ELEMENT NO. 2AF 643
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED OAQPS/AQMPA Guideline
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This is a revision of the original Volume 10 of the Air Quality Maintenance Planning and Analysis Series, published in September 1974.

16. ABSTRACT

This document is a revision of the original Volume 10 (EPA-450/4-74-011: "Reviewing New Stationary Sources") of the EPA Guidelines for Air Quality Maintenance Planning and Analysis. It provides basic modeling techniques for estimating the air quality impact of new (proposed) stationary sources. The revision is in a more readily useable format and incorporates changes and additions to the technical approach. Also, a simple screening procedure has been added. The techniques are applicable to chemically stable, gaseous or fine particulate pollutants. An important advantage of the technique is that a sophisticated computer is not required. A pocket or desk calculator will generally suffice.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	New Source Review	
Airborne Wastes	Air Quality Maintenance	
Meteorology	Point Sources	
Micrometeorology	Emissions	
Atmospheric Diffusion	Stack Design	
Atmospheric Models		

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* None	21. NO OF PAGES
	20. SECURITY CLASS *(This page)* None	22. PRICE

EPA Form 2220-1 (9-73)